A pilot study to compare clinical and radiographic success of a non-root instrumentation non-vital pulpotomy and a traditional pulpectomy

By

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ABSTRACT

Current options for management of necrotic primary molars include pulpectomy or extraction but are not always appropriate for children with limited cooperation. A pulpotomy may be better tolerated but there is little evidence for its effectiveness. This pilot study assessed clinical and radiographic success of a pulpectomy, pulpotomy and pragmatic pulpotomy, and the feasibility of conducting a randomised controlled trial.

4-9 year olds with non-vital primary molars were recruited and randomly allocated to receive a pulpectomy or a pulpotomy. If they could not tolerate rubber dam, a pulpotomy was provided without isolation (pragmatic group).

22 molars were enrolled (17.7% recruitment rate). Insufficient cooperation was a common reason for non-inclusion. 13 of 16 teeth (81.3%) returned for follow-up. At 6 months, 2 of 3 pulpectomised teeth, 5 of 7 teeth with a pulpotomy and 2 of 4 teeth with a pragmatic pulpotomy were successful. At 24 months, success rates were 1 of 1 tooth, 2 of 3 teeth and none of 3 teeth respectively. 4 pulpotomised and 1 tooth in the pragmatic group exfoliated early.

The small numbers limit the conclusions that can be drawn but the pulpotomy technique appears to warrant further research. A different study design may improve recruitment.

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experience post-treatment. She also provided much needed emotional support throughout the study period.

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CHAPTER 1: INTRODUCTION

1.1 The role of primary teeth

Primary or milk teeth are often thought of as unimportant as they exfoliate (loosen and fall out by natural dissolution of the roots) and are eventually replaced by permanent teeth. However primary teeth begin to appear at 6 months, with the primary incisors erupting first followed by the first primary molars at 13-19 months old and second primary molars and primary canines at 23-33 months Nelson et al. (2010), (Kubota et al., 1992). The primary molars do not exfoliate until the premolars erupt at 10-12 years old so can be present in the mouth for up to 10 years, longer if no permanent successor is present (Nelson et al., 2010).

During this time the primary dentition plays an important role in space maintenance, proper mastication and aesthetics. It is therefore important to maintain the primary dentition in a non-pathologic and healthy condition to prevent loss of space by forward drifting of the permanent molars, stop aberrant habits such as tongue thrust developing due to gaps between anterior teeth, improve phonetics by providing appropriate structures for the oral musculature to use to make sounds and to minimise future orthodontic treatment need (Kubota et al., 1992). Maintenance of the primary dentition can simplify treatment of any skeletal discrepancies between the jaws which lessens the future costs to parents and children of multiple visits to orthodontic practitioners and the potential removal of healthy permanent teeth to alleviate crowding. It also reduces NHS costs for children's orthodontic treatment and may allow improved access and shorter waiting times for more complex orthodontic patients.

1.2 Dental caries in children

Although national epidemiological surveys have shown a general decline in the degree of dental caries (decay) in 5 year old children, there does appear to be a levelling off with approximately 30-40% of 5 year olds experiencing decay in the last 2-3 decades (Figure 1) (Lader et al., 2005, Health and Social Care Information Centre, 2015). The most recent National Health Service Dental Epidemiology Programme surveys (2007/2008, 2011/2012, 2014/15) and the 2013 Children's Dental Health survey (CDH 2013) showed a reduction in the caries experience of children this data cannot be directly compared with previous studies as parents were required to give positive (opt-in) consent for their child to participate which may have introduced some bias (Davies et al., 2012, Health and Social Care Information Centre, 2015). In addition, CDH 2013 did not include Scotland which would have altered the overall results as Scotland has higher levels of decay than the rest of the United Kingdom. Previous surveys have also demonstrated that the average number of dentinally decayed, missing (due to decay) and filled primary teeth ($d_3$mft) in 5 year old children has remained stable at approximately 1.5 teeth for the last 2-3 decades (Davies et al., 2012, Lader et al., 2005). Although the 2013 Children's Dental Health Survey shows this to have dropped to 0.9 teeth, the average number of teeth with clinical decay (confined to enamel) was still 1.8 (Health and Social Care Information Centre, 2015).

National surveys have also demonstrated that the majority of decay occurs in children living in the most deprived areas with increased decay experience in those receiving free school meals and a positive correlation between $d_3$mft and increasing social deprivation (Fig 2) (Health and Social Care Information Centre, 2015, Lader et

al., 2005). Amongst those children with decay experience ($d_3$mft >0) the average $d_3$mft was 3.0 in 2013 and 3.38 in 2012 (Health and Social Care Information Centre, 2015, Davies et al., 2012). In addition, the majority of decayed teeth are left untreated with an average 0.1 teeth filled out of 0.9 decayed teeth (11%) or in those with decay 0.4 out of 3.0 teeth (13%) (Health and Social Care Information Centre, 2015). This is known as the care index (ft/$d_3$mft) and it has remained at a low level (11-14%) for the past 30 years (Davies et al., 2012, Lader et al., 2005). There are many reasons why it is so low, including conflicting evidence regarding whether to restore primary teeth or not, difficulty in accessing NHS dentistry and poor cooperation of child patients.

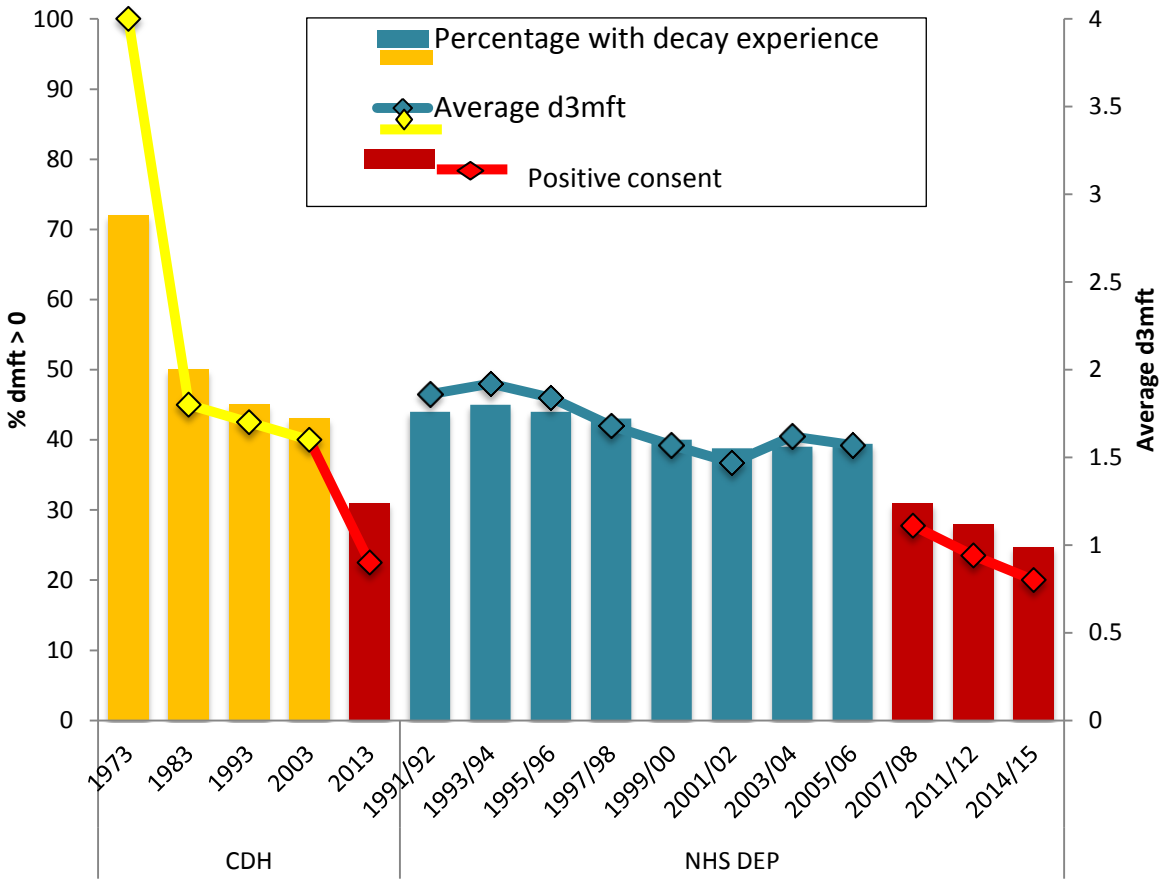


Figure 1: Results of caries surveys of five-year-olds in England from the Children's Dental Health Surveys and NHS Dental Epidemiology surveys, 1973 to 2015

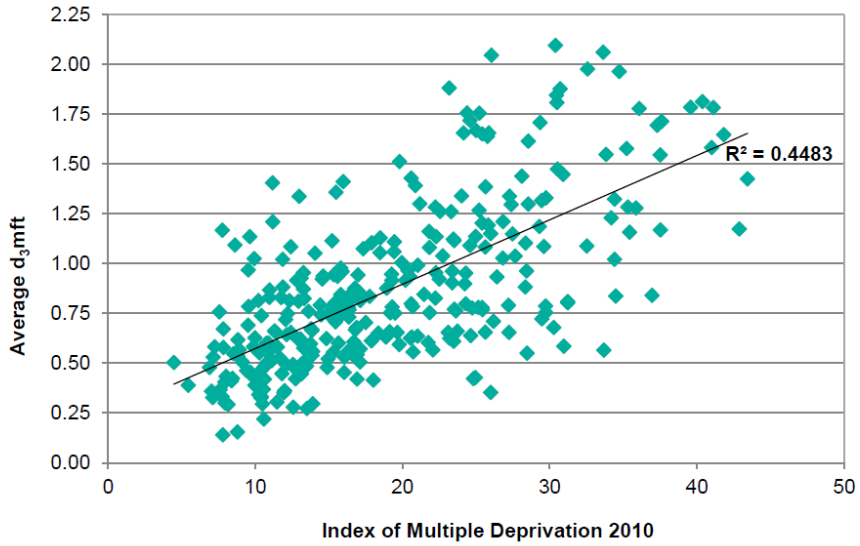


Figure 2: Correlation between number of dentinally decayed, missing (due to decay) and filled teeth (d3mft) among 5 year old children and Index of Multiple Deprivation (IMD 2010) score. Lower-tier local authorities in England, 2012 (Davies et al., 2012)

1.3 Management of caries in children

The management of dental caries in primary teeth is constantly evolving as new evidence emerges. Recent research has even questioned whether caries removal or fillings (restorations) are actually required in primary teeth. Studies by Tickle et al. (2002) suggest that symptomless carious primary teeth managed in general dental practice exfoliated naturally whether they were filled or not and the placement of a restoration did not have an effect on future pain or infection. Innes et al. (2011) found that sealing in caries by using a preformed metal crown without any caries removal, the so-called Hall technique, was more successful than conventional fillings in primary molars when assessing occurrence of symptoms and the longevity of the restoration. These studies have prompted the development of the FiCTION trial which aims to investigate whether conventional management of caries (mechanical removal under local anaesthetic), biological management of caries (sealing caries with adhesive materials or preformed metal crowns) or prevention alone have any

effect on the child's experience of pain or infection (Innes et al., 2013). The results from the FiCTION trial combined with the already low care index for restoration of primary teeth could lead to a proportion of children with no experience of dental treatment under local anaesthetic (LA) who have extensive caries and primary molars causing pain and infection (non-vital teeth). The only way to manage this situation may be extractions under general anaesthetic (GA) for an increased number of children unless a more acceptable treatment method is found for these teeth. The number of children requiring GA for dental treatment is already increasing with dental caries now the most common reason for a hospital admission in 5-9 year olds (Dental Public Health Intelligence Programme, 2013).

1.4 Rationale for study

This study aimed to investigate alternative, simpler restorative options for infected (non-vital) primary molars. A more acceptable treatment may potentially reduce the number of less cooperative children requiring GA and result in more children retaining primary molars, leading to fewer orthodontic complications at a later stage. This could reduce the financial costs associated with treatment under general anaesthetic and complex orthodontic treatment for children. It may also improve children's quality of life, reducing pain and infection from decayed teeth, preventing the removal of multiple teeth so improving appearance and function, especially eating and communication. Children may also have a more positive experience at the dentist which may improve compliance for future treatment and advice given by dental professionals to prevent further dental disease.

CHAPTER 2: LITERATURE REVIEW

2.1 Primary molars

2.1.1 Anatomy

Primary molars have a bulbous crown with a pronounced buccal cervical ridge and are wider mesio-distally compared to their crown length. This shape results in broad mesial and distal contact points with adjacent teeth which gives a large area for plaque stagnation and caries can be quite extensive before it is seen clinically. The enamel is thin and there is little dentine between the large pulp chamber which contains the nerve and blood supply of the tooth and the enamel, especially over the mesial pulp horn, which means that the pulp is more readily affected by caries (Nelson et al., 2010, Hargreaves et al., 2011). The mid coronal pulp in primary teeth is more vascular than in permanent teeth due to an increased number of small blood vessels and it has been suggested that this may lead to an increased inflammatory response to caries compared to permanent teeth (Rodd and Boissonade, 2005).

Primary molar roots are long, slender and widely flared to enable to development and eruption of the permanent successor tooth underneath. They have the same number and position of roots as the corresponding permanent molars but there is large variation in the number of root canals (Ahmed, 2013). After completion of root formation there is only one root canal in each of the roots but dentine is continually deposited internally which divides the root into separate canals often with fine connections between them (Figure 3). It is also thought that secondary dentine is deposited in the root canals after physiological root resorption occurs thus changing the root canal morphology over time (Hargreaves et al., 2011, Ahmed, 2013).

Figure 3: Three-dimensional tomographic images of a maxillary second primary molar. A, Mesial view of primary molar with four root canals. B, Same tooth from the distal view (Hargreaves et al., 2011)

2.1.2 Effect of caries on the pulp in primary molars

It was previously thought that once caries advances towards the pulp chamber, inflammation progresses from the pulp horns to the coronal pulp and then into the roots. Duggal et al. (2002) found that in primary molars where less than half of the distance between the cusps was carious, 63% of teeth showed pulpal inflammation extending to the pulp horn which increased to 70% when more than half of the intercuspal distance was carious. Once the caries affected more than half of the intercuspal distance, 11.6% showed signs of inflammation in the radicular pulp compared with none of the teeth in the less than half intercuspal width group. These data, combined with evidence from earlier studies suggesting an increased early inflammatory response to caries in primary teeth, lead to the theory that primary molars with interproximal caries and marginal ridge breakdown should be treated by removal of the pulp tissue in the crown of the tooth only (vital pulpotomy) (Kopel, 1992, Rayner and Southam, 1979, Magnusson, 1980). This technique leaves vital

non-inflamed pulp tissue in the root canals and allows the tooth to exfoliate naturally without symptoms. However more recent work found that in grossly carious primary teeth the pulp vascularity increases by enlarging the blood vessels in the area of the pulp horn only and does not spread as widely to the rest of the pulp as previously thought (Rodd and Boissonade, 2005).

If the inflammation has progressed further and the radicular pulp is irreversibly inflamed this may be seen clinically as a hyperaemic or hyperalgesic pulp and on removal of the coronal pulp the remaining radicular pulp will not stop bleeding. This may also manifest as spontaneous or continuous pain (Seltzer and Bender, 1984). However, the correlation between symptoms and pupal status is poor and Rodd and Boissonade found no difference in pulp vascularity between asymptomatic and painful teeth (Rodd and Boissonade, 2005, Guthrie et al., 1965).

Inflammation of the pulp and the tissues surrounding the end of the root (periapical tissues) can cause pathological changes in the normal physiological resorption of the roots of primary molars and this may result in changes to the root canal morphology due to deposition of secondary dentine and altered position of the root tip (apex) (Ahmed, 2013).

2.1.3 Differences in the management of non-vital primary and permanent teeth

Once the pulp is infected the anatomy of the pulp and root canals in primary molars makes endodontic (root canal) treatment more difficult. The thin pulp chamber floor leads to infection spreading to the furcation region between the roots as well as periapically. It also allows permeation of chemicals placed in the pulp chamber,

which means all medications, sealers, irrigants and dressings used must be biocompatible. Primary molar roots are more curved and have oval shaped canals with variable connections. There are often periodontal-endodontal communications. Determination of the exact location of apical foramen in primary teeth is also complicated by physiological and pathologic root resorption which can extend into the root canal creating additional communications with the periapical tissues (Ballesio et al., 2002). These factors make complete chemomechanical removal of necrotic or infected pulp tissue in primary molars more difficult than in permanent teeth. The materials used for root canal obturation in primary teeth also differ from those used in permanent teeth as they must be capable of resorbing at the same rate as the physiological resorption of the roots and they must be biocompatible in case of extrusion into the periapical or furcation areas (Ballesio et al., 2002).

Taking all of these factors into account the management of a primary molar with irreversible pulpitis or a necrotic, non-vital pulp is somewhat different from the endodontic cleaning, shaping and obturation of root canals which is standard practice in a non-vital permanent molar even before the issues of patient management are considered.

2.2 Management of non-vital primary molars

As we have discovered the management of the non-vital primary tooth is different from that of the non-vital permanent tooth. In permanent teeth the options would be root canal treatment and obturation with a non-resorbable material or extraction and management of the resulting space. In primary teeth the options include extraction with or without maintenance of the space for the permanent

successor, pulpectomy which involves removal of all of the infected and necrotic pulp tissue followed obturation with a resorbable paste or pulpotomy where only the coronal portion of the pulp is removed and the infected root canals are managed chemically until physiological root resorption and exfoliation of the tooth occur. There are various advantages and disadvantages to each of these techniques.

2.2.1 Extraction

Extraction of a non-vital primary molar is 100% successful in eliminating the possibility of chronic infection or pain from the tooth. However, the premature loss of primary molars can result in loss of space for the permanent successors. More space is lost in the mandible than the maxilla, for a primary second molar than a primary first molar and the earlier a tooth is removed (Owen, 1971, Breakspear, 1951). This can result in the need for significant orthodontic treatment in the future and even the loss of a healthy premolar to correct crowding or allow eruption of other permanent teeth. The loss of space can be prevented by the use of an orthodontic brace called a space maintainer but these are not appropriate for use in children with a high caries rate and/or poor oral hygiene as they can result in plaque retention and caries around the remaining primary teeth. The primary molar is therefore the best space maintainer and every attempt should be made to restore and retain it wherever possible.

If the decay is so extensive that the tooth is unrestorable, there is a perforation of the pulp chamber floor or there is evidence of internal resorption or significant root resorption then extraction of the tooth is the only option (Rodd et al., 2006). However, extraction of a primary tooth requires sufficient cooperation from the child for LA

administration followed by the sensation of pulling and pushing on the tooth during the procedure. This can cause significant discomfort if there is an acute infection or in a young child with longer roots and therefore children may require GA to complete the extraction.

GA always carries a risk of morbidity due to respiratory difficulty or sudden cardiovascular collapse and over the last three decades there have been 1-2 deaths a year from dental GA; a risk of 1:270,000-400,000 (Padfield, 2000, Jenkins and Baker, 2003). Guidelines on the use of GA for dental treatment in children therefore advise completion of all treatment required in a single GA to reduce the risks of repeat GA (Davies et al., 2008, Adewale et al., 2011). If a child has been unable to tolerate restorative treatment in other carious teeth prior to the GA, this may necessitate extraction of multiple carious teeth including those with minimal restorable cavities.

GA is also a costly treatment option. Data from the Dental Public Health Intelligence Programme (2013) shows that dental caries is now the most common reason for a hospital admission in 5-9 year olds with over 25,000 children in this age range being admitted for dental extractions in 2012-2013 at a cost of £30 million to the NHS for children under 18 years (Department of Health, 2013). Their figures also demonstrate higher numbers of hospital admissions in more deprived areas, i.e. those with increased levels of decay. If the number of children requiring extractions could be reduced by providing more acceptable treatment options for children, then this may result in significant cost savings for NHS trusts as well as health benefits for children.

2.2.2 Pulpectomy

If a tooth is restorable and the patient is cooperative and not medically compromised then the gold standard treatment for a non-vital primary molar is a pulpectomy (Rodd et al., 2006). A pulpectomy involves removal of all dead pulp tissue from the pulp chamber and the root canals and is followed by obturation of the root canals with a resorbable paste. Sweet (1930) first described the use of zinc oxide and eugenol to fill the root canals of 'pulpless' primary teeth in 1930 and the first one-visit pulpectomy study was carried out by Gould (1972).

Pulpectomy in vital primary molars obturated with zinc oxide paste has a clinical success rate between 86 – 91% and a radiographic success rate of 67-72%. This was a better success rate than vital pulpotomies with ferric sulphate and equivalent to vital pulpotomies with formocresol (Payne et al., 1993, Casas et al., 2004, Roberts, 1996, Redig, 1968, Yacobi et al., 1991). However, the numbers in these studies were small and there were no clinical or radiographic signs of infection or necrosis because the teeth were vital. In non-vital primary teeth, the success of pulpectomies depends on the technique, irrigants, medicaments and obturation paste used but clinical success ranges from 65-100% and radiographic success from 28-100% (see Table 1).

However, a pulpectomy requires sufficient cooperation for LA infiltration, rubber dam placement, periapical radiographs and instrumentation of the root canals. It can be time consuming and dentists often feel extraction is a more appropriate option especially in younger children. A direct quote from a primary dental practitioner involved in the pilot study for the FiCTION trial stated '*Do you really want to be putting a rubber dam, and putting files down Ds and Es when there's 4s and 5s*

underneath?' which highlights the concerns that non-specialists have about providing pulpectomy treatments for children even those children who are cooperative in the dental chair (Marshman et al., 2012).

Authors	No of subjects	Technique & follow up	Obturation material	Irrigant	Coronal restoration	Success
Hendry et al. (1982)	42	Animal experiment Primary teeth of dogs Barbed broaches Filed to 1mm of radiographic apex 1/7- 4/52 follow-up	Calcium hydroxide and camphorated parachlorophenol v no filling v ZOE	Sterile saline	ZOE	Highest mobility score no filling, lowest Calcium hydroxide More PDL widening and bone loss in no filling, least in ZOE group
Coll et al. (1985)	41 (29 followed up at 5+ yrs)	In vivo Single visit Filed short of apex to resistance point up to size 40 Paper points moistened with formocresol placed in canals 5 mins 6-36 months follow-up 5+ yrs follow-up	ZOE	Sodium hypochlorite	?	6-36 months 80.5% 5+ yrs 86.1%
Garcia-Godoy (1987)	55 (45 follow-up)	2 visit 1st visit Barbed broach and excavators Left open if exudate uncontrolled KRI 3 in pulp chamber for 3-7 days Incised fistulas 2nd visit Filed with Hedstrom 11mm 6-24 months follow-up	KRI 1 ZOE lining	Sodium hypochlorite and hydrogen peroxide	PMC	Overall: 95.6% 2 failures at <12/12

Reyes and Reina (1989)	53 ?loss to follow-up (only 10 pts at 24 months)	Prospective Single visit File to 16mm size 40 24 months follow-up	KRI, Calcium Hydroxide + Formocresol	5% sodium hypochlorite	PMC	Clinical: 6/12 100% 12/12 100% 24/12 80% Radiographic: 6/12 73.6% 12/12 28.6% 24/12 30% ?all failures resorption/ mobility ?physiological
Barr et al. (1991)	62	Single stage Filed to 1-2mm from radiographic apex 12 – 74 months follow-up	Formocresol + eugenol	Water	PMC	Overall 82.3%
Holan and Fuks (1993)	78 34 ZOE 44 KRI	Retrospective review Single visit Barbed broach to remove pulp tissue Radiographically determined apex Filed to size 35 6-84 months follow-up	KRI v ZOE	Hydrogen peroxide and saline	IRM PMC 4/52 later	Overall: KRI 84% ZOE 65%
Thomas et al. (1994)	36	Single visit Extirpation of pulp but no filing of canal walls 3 months follow-up	Iodoform and zinc oxide	Saline	?ZOE	Overall: 94.4% but failures due to loss of interim restoration

Rosendahl and Weinert-Grodd (1995)	2	Case report 2 visits Left open for 1/7 Filed to size 35-40 1mm from radiographic apex 36 months follow-up	Calcium Hydroxide	1% Sodium hypochlorite	Zinc oxide cement and amalgam	100%
Coll and Sadrian (1996)	81	Retrospective review 30 incisors and 51 molars Technique as per Coll et al (1985) 20-177 months follow-up	ZOE	-	-	Overall molar:74.5% No preoperative resorption 91.7% Minimal resorption 82.8% Excessive root resorption 23.1% Short fills 86.5% To apex 88.9% Long fills 57.7%
Nurko and Garcia-Godoy (1999)	33	Retrospective review Single visit Barbed broaches and excavators Filed to size 40 22 months follow-up	Vitapex	Water	PMC	100%
Mani et al. (2000)	60	Single visit unless uncooperative Barbed broaches Filed to size 30-35 1mm from radiographic apex 6 months follow-up	Calcium hydroxide v ZOE	5% sodium hypochlorite and 0.5% IV metronidazole solution	ZOE paste	Overall: ZOE 83.3% Calcium hydroxide 86.7%
Nadkarni and Damle (2000)	60	RCT Single visit	Calcium hydroxide v	2.5% sodium hypochlorite	PMC	Overall: ZOE 88.57%

		Primary mandibular molars Barbed broaches Working length radiograph size 15 files 1mm short of apex Shaped with Hedstrom files to max size 40 9 months follow-up	ZOE (using root canal pressure syringe system)	and saline		Calcium hydroxide 94.28%
Ballesio et al. (2002)	50	2 visits 1st visit: file canals 2-3mm beyond orifices of canal Mix of macrolide antibiotic and glycerine Repeated if no improvement and extracted if no improvement after 8-10 days 2nd visit: filled 36 months follow-up	Small amount of macrolide antibiotic and glycerine paste + ZOE	10 vol Hydrogen peroxide and 3% sodium hypochlorite	3rd visit PMC	Overall: Immediate 96% 1.5-3 yrs 93%
Mortazavi and Mesbahi (2004)	58 (52 follow up)	RCT 2 visits 1st visit Pulpotomy and formocresol placed in pulp chamber for 1-2 weeks Antibiotics if acute alveolar abscess at 1st visit 2nd visit filing to 1-2mm from radiographically determined apex 10-16 months follow-up	ZOE v Vitapex	Sterile saline	Posterior: amalgam Anterior: composite	Overall: Vitapex 100% ZOE 78.5%
Moskovitz et al. (2005)	174	Retrospective review Single visit Filed to radiographic working	Endoflas	3% hydrogen peroxide and saline	ZOE 1/12 later PMC,	95% after 6 months 84% radiographic success

		length to size 30 6-77 months follow-up			composite or amalgam	Overall 82% SSC 96%, amalgam/composite 92%, temporary restoration 28.6% Flush fill 85% Underfilled 91.2% Overfilled 76.3%
Ozalp et al. (2005)	80	RCT Single visit unless uncooperative Barbed broaches Filed to size 30-35 1mm from radiographic apex 18 months follow-up	ZOE v Calcicur v Sealapex v Vitapex	5% sodium hypochlorite followed by 0.5% metronidazole solution	Amalgam	Clinical: ZOE 100% Sealapex 90% Calcicur 80% Vitapex 100% Radiographic: ZOE 100% Sealapex 90% Calcicur 80% Vitapex 100% Failed 6-8/12
Bawazir and Salama (2006)	50	RCT Single visit Barbed broaches Filed to size 35 Hedstrom file in all canals except palatal canal of maxillary molar increased to size 50 to 1mm from radiographic apex Compared mechanical and handheld spiral paste fillers 6 months follow-up	ZOE	Normal saline Final irrigation with physiological saline Paper points moistened with one fifth diluted formocresol for 5 minutes	PMC	Clinical 94% Radiographic 81%
Trairatvorakul and Chunlasikaiwan	54	RCT Single visit	ZOE v Vitapex	2.5% sodium hypochlorite	PMC	Overall: 6 months

(2008)		Removed pulp with barbed broach Filed to size 35- 40 to 1mm from electronically determined apex 12 months follow-up				ZOE 85% Vitapex 89% 12 months ZOE 89% Vitapex 89%
Ramar and Mungara (2010)	96	RCT Single visit Mandibular primary molars Working length radiograph Filed to size 30-35 to 1mm from apex 3, 6 and 9 months follow up	ZOE and iodoform v Metapex v Endoflas	2.25% sodium hypochlorite and 0.12% chlorhexidine gluconate	PMC	Clinical: ZOE 100% Metapex 96.8% Endoflas 100% Radiographic: ZOE 81.1% Metapex 72.5% Endoflas 90.3% Overall: ZOE 90.5% Metapex 84.7% Endoflas 95.1%
Subramaniam and Gilhotra (2011)	45	RCT Single visit 3, 6, 12and 18 months follow up	Metapex v Endoflas v ZOE	Saline and 1% sodium hypochlorite	PMC 1 week later	Overall: Metapex 100% Endoflas 93.3% ZOE 93.3%
Louwakul and Prucksathamrongkul (2012)	64	RCT Single visit Mandibular primary molars only Filed to size 35-40 to 1mm from radiographic apex 6,12 and 18 months follow-up	Vitapex	2% chlorhexidine v Normal saline solution	PMC	Overall: 6 months NSS 83% CHX 100% 12 months NSS 93% CHX 97%

						18 months NSS 97% CHX 93%
Pramila et al. (2015)	129	RCT Single visit unless extra-oral swelling Mandibular primary molars only Barbed broach and Hedstrom files up to max size 35 to 1-2mm from apex Working length determined from preoperative radiograph 6, 12 and 30 months follow-up	RC fill (ZOE with iodoform) v Vitapex v Pulpdent (ZOE)	Saline Final irrigation 2% chlorhexidine	PMC	Clinical: 100% 6, 12 and 30 months Radiographic: 6 months RC Fill 89% Vitapex 80% Pulpdent 97% 12 months RC Fill 94% Vitapex 82% Pulpdent 97% 30 months RC Fill 94% Vitapex 90% Pulpdent 97%

Table 1 : Review of literature relating to pulpectomy treatments in primary molars (PMC = preformed metal crown, ZOE = zinc oxide eugenol)

2.2.3 Formocresol pulpotomy

A simpler option that was often used in the past for children with insufficient cooperation for a pulpectomy was a formocresol pulpotomy. This involves removing the coronal pulp and any accessible pulp tissue in the roots and then 'fixing' the remaining pulp tissue with formocresol. Massler and Mansukhanl (1959) found that after 7-14 days pulp adjacent to the formocresol showed signs of fixation, in addition to the germicidal action of the formocresol. There was also a broad zone of inflammatory cells extending to normal tissue at the apex suggesting deeper chemical action.

Roberts (1996) conducted a prospective study of formocresol pulpotomies without any mechanical debridement of the root canals. A zinc oxide eugenol formocresol mixture was placed into the pulp chamber and the tooth restored with a preformed metal crown. He found a success rate of 28 of 33 teeth (84.8%) which compares well with pulpectomy studies. Any recurrence of infection occurred after a mean interval of 1.6 years, giving time for cooperation to improve and allow extraction without a GA. Similar success rates were described by Bly (1970) and Feinglass (1973) by applying formocresol on a cotton pellet to the root canals for 5-7 minutes or sealing in for 1 week and then restoring with zinc oxide eugenol mixed with one drop formocresol. Velling (1961) and Droter (1963) also sealed formalin into necrotic teeth for 3-5 days and then restored with zinc oxide eugenol and a preformed metal crown or amalgam. Droter found 100% success in 63 teeth over 2 years and in Velling found only 5 of 863 (0.6%) cases failed and these were due to perforation of the root canal walls or bifurcation area. O'Riordan and Coll (1979) suggested an alternative technique using paper points moistened with one fifth dilution formocresol inserted into instrumented

root canals for five minutes. This prevented long term exposure of the surrounding soft tissues to formaldehyde but fixed any pulp tissue which could not be removed directly by instrumentation. This technique was used by Bawazir and Salama (2006) and after 6 months the clinical success rate was 94% and radiographic success was 81%.

For many years the formocresol pulpotomy was therefore a standard technique for the management of non-vital primary molars in children who were not cooperative enough for a pulpectomy or administration of LA and extraction of the tooth. It was also a useful technique for necrotic teeth which were important for space maintenance as it allowed teeth to be retained for several years until exfoliation or the child's cooperation improved. However, several concerns were raised over the safety of formocresol and formaldehyde. Systemic absorption in the region of 0.38μM formocresol was found during pulpotomy treatment and although this was not enough to be toxic to the liver or kidneys, uptake was noted in periodontal ligament, bone, dentine and urine (Myers et al., 1978, Ranly and Horn, 1987, Ranly, 1985). Application of 1 to 16 μM formaldehyde for 15 minutes in monkey kidney cells was found to produce mutational changes and mutations of human lymphoblastoid cell lines were found with concentrations in excess of 130μM for 2 hours (Goldmacher and Thilly, 1983, Nocentini et al., 1980). Animal studies have also shown precancerous and cancerous changes in epithelia following prolonged contact with formaldehyde (Swenberg et al., 1980, Muller et al., 1978). This may be a risk in teeth filled with a paste containing small levels of formaldehyde at a young age as long term exposure will occur. In 2004, the International Agency for Research on Cancer (IARC) concluded that formaldehyde is carcinogenic to humans, having

demonstrated an increased risk of nasopharyngeal carcinomas (International Agency for Research on Cancer, 2004). Therefore the use of formocresol for non-vital pulpotomies in primary teeth is now contraindicated and research continues to find alternative techniques and medicaments with similar success rates in non-vital primary molars.

2.2.4 Other alternatives

Recently dentists have looked for alternatives to the instrumentation of root canals which is the part of pulpectomy treatment which is time consuming and difficult for children to tolerate and dentists to perform. Boeve and Dermaut (1982) found 87% success in a mix of necrotic and vital primary molars using formocresol for a few seconds and then sealing with Tempophore and zinc oxide eugenol. They claimed that the iodoform in Tempophore provided the antiseptic and fixing action of the paste and formocresol disinfected only. It has therefore been suggested that a pulpotomy technique could be carried out without using formocresol or instrumenting the canals by disinfecting with an irrigant and then fixing with an iodoform containing paste.

A mixture of 3 antibiotics (metronidazole, ciprofloxacin and minocycline) has been used to sterilise the root canals of immature permanent incisors prior to revascularisation techniques and it has also been used to reasonable effect in non-vital primary molars. Prabhakar et al. (2008) used a mixture of 1 part ciprofloxacin to 3 parts metronidazole and 3 parts minocycline and when the radicular pulp tissue was extirpated found a clinical success rate of 100% and radiographic success of 83.3% after 12 months. When this was compared with non-extirpation of the root canals the clinical success dropped to 93.3% and radiographic success was only

36.7% (Prabhakar et al., 2008). Pinky et al. (2011) had good clinical success when comparing 1 part ciprofloxacin, 3 parts metronidazole and 3 parts minocycline with 1 part ciprofloxacin, 3 parts ornidazole and 3 parts minocycline with 100% of teeth in both groups asymptomatic at 6 months and 90% of the metronidazole group and 100% of the ornidazole group successful at 12 months. In this study the root canals were not instrumented at all but the canal orifices were widened with round burs and irrigated with saline. Radiographically the first group showed bone regeneration in 55% teeth at 12 months and bone loss in 10%, the second group showed regeneration in 60% and no change in bone in the remaining 40%. Chemical rather than mechanical disinfection of the root canal system may therefore be possible. However success rates were low in a study by Trairatvorakul and Detsomboonrat (2012), where they used a 1:1:1 ratio triple mix preparation and did not instrument the root canals. After 2 years follow-up the clinical success in mandibular primary molars was 75% and radiographic success only 36.7%. Nakornchai et al. (2010) used a similar technique, using 1:1:1 antibiotic paste and non-root instrumentation and obtained better results than pulpectomies using iodoform and calcium hydroxide paste after 12 months - 96% clinical success in both groups, 76% radiographic success in the antibiotic group compared with 56% in the pulpectomy group. These techniques are certainly worth considering in less cooperative children.

One technique which has been described in the Scottish Dental Clinical Effectiveness Programme (SDCEP) guidelines in 2010 for children who cannot tolerate local anaesthetic or rubber dam isolation is removal of caries, unroofing the pulp chamber and removing necrotic coronal pulp with a slow speed handpiece or sharp excavator (like a pulpotomy) and removal of as much necrotic tissue as

possible from the entrances of the root canals using a straight probe. The pulp chamber is then irrigated with water from the 3 in 1 or local anaesthetic solution and dried with a cotton wool pledget. The coronal section of the root canals is filled with calcium hydroxide or zinc-oxide eugenol and the pulp chamber backfilled with zinc-oxide eugenol paste using firm pressure which would force some of the calcium hydroxide or zinc-oxide eugenol paste into the necrotic root canals aiding chemical disinfection. A preformed metal crown is then placed. This has been termed 'the non-root canal instrumentation or Scottish pulpotomy'. No evidence for the efficacy of this technique is provided within the guidelines nor could any results for this technique be found within the literature in 2011. Some clinicians are cautious about the use of this technique and leaving behind necrotic pulp tissue. However as previously discussed filing the root canals in a primary molar will not remove all pulp tissue due to the anatomy of the root canals and other pulpotomy treatments, with and without formocresol, which disinfect and fix the tissue rather than remove it have comparable success rates to pulpectomy.

This 'Scottish pulpotomy' could therefore offer a much simpler treatment for the dentist and child if it is found to have good success in reducing the signs and symptoms of pain and infection. It may help to maintain the tooth until exfoliation or there is sufficient cooperation for extraction or pulpectomy with local anaesthetic and rubber dam isolation or any other teeth have been satisfactorily restored before undergoing extractions under GA.

2.2.5 Current guidelines

In 2006, the British Society of Paediatric Dentistry (BSPD) updated its clinical guidelines on pulp therapy for primary molars in response to research on primary pulp biology and the press release from IARC in 2004 (Rodd and Boissonade, 2001, Rodd and Boissonade, 2005, Rodd et al., 2006, International Agency for Research on Cancer, 2004). In view of the limited evidence regarding alternative pulpotomy techniques, these guidelines recommend pulpectomy as the gold standard for restorable non-vital primary molars. If the patient does not have sufficient cooperation for a pulpectomy, then extraction would be indicated.

The American Academy of Paediatric Dentistry (AAPD) suggests that pulpectomy is the only option for irreversibly infected or necrotic primary teeth with minimal or no root resorption. They state that pulpotomy should not be undertaken if there is evidence of radicular pathology (American Academy of Paediatric Dentistry, 2014).

The Scottish Dental Clinical Effectiveness Programme (SDCEP) published their own guidelines in 2010. These suggest that clinicians should consider a pulpectomy for restorable non-vital primary molars if the child will accept rubber dam placement. However they offer an alternative treatment for non-compliant children, the previously described ‘non-root canal instrumentation/ Scottish pulpotomy’. There is no evidence behind the use of this technique and there are differing opinions about the appropriateness of leaving necrotic tissue behind.

2.3 Pulpectomy treatments in primary molars

2.3.1 Mechanical cleaning of pulp chamber and root canals

Due to the complexity of the root canal system in primary molars full mechanical cleaning with endodontic files is not possible in the same way as in permanent teeth. Nevertheless an attempt must be made to remove as much necrotic tissue as possible through instrumentation of the root canals. The pulp chamber must be fully unroofed to ensure removal of all necrotic tissue from the chamber and allow access to the divergent root canals. As the root canals are narrower than their permanent counterparts and are often ovoid in shape, small endodontic files no wider than size 40 should be used (see Table 1). This enables the canals to be widened sufficiently to allow thorough irrigation without risk of root canal wall perforation.

Determination of the apical foramen in primary molars can be difficult due to physiological root resorption and the superimposition of the permanent successor on radiographs (Ballesio et al., 2002, Garcia-Godoy, 1987). Mechanical preparation of the apex of primary teeth is also different to the preparation of permanent teeth as the root canals are obturated with a resorbable paste so an apical stop is not required to pack the filling material against. In addition, care must be taken not to instrument through the apex as this may cause damage to the developing permanent successor (Ballesio et al., 2002). Any mechanical preparation of the root canal should be carried out to within 1-3 mm of the estimated apex to reduce the risk of damage to the permanent successor. This is the technique described in previous studies on pulpectomies shown in Table 1.

The approximate length of the root canals should therefore be determined either from pre-operative periapical radiographs by calculating the ratio of crown height to root length clinically and radiographically or by taking working length radiographs with

endodontic files in the root canals. Radiographs showing the apex of the tooth can be difficult to take in children who have small mouths and limited cooperation.

Electronic apex locators (EAL) are increasingly being used to reduce the radiographic exposure and the operative time taken, as well as improve the ease of the procedure for children (Ahmad and Pani, 2015). Oznurhan et al. (2014) found the accuracy of EALs in primary molars to be 70-95.82% in vivo and a meta-analysis showed that although there was a statistically significant mean difference between the EAL measurement and the actual root length this was only 0.109 mm shorter which is not clinically significant. In addition, the same meta-analysis showed high correlation between the measurements (Ahmad and Pani, 2015). The accuracy in finding the actual apex can be affected by the size of the apical foramen, type and size of measuring file and the conductivity of the pulp in any communications between to the canals (Enes Odabaş et al., 2011). This would suggest that electronic measurement of working length may be less accurate in roots with more resorption. Enes Odabaş et al. (2011) found a reduced accuracy in resorbed compared to unresorbed roots but it was not statistically significant difference and the meta-analysis by Ahmad and Pani (2015) showed no statistically significant difference in measurement accuracy between teeth with or without root resorption.

2.3.2 Irrigation and chemical cleaning of pulp chamber and root canals

As it is impossible to completely remove necrotic tissue from primary root canals through mechanical cleaning alone, chemical and pharmacological cleaning of the

root canals becomes very important in the endodontic treatment of primary teeth. Any irrigants and medicaments used should therefore have antiseptic and antibiotic properties. However, the limited cooperation of children means they may not tolerate rubber dam isolation and the rubber dam placed may not be fully watertight due to the cavity in the tooth. Irrigants which are less irritant to the tissues, less toxic and more pleasant tasting are therefore preferable. Table 1 shows the variety of irrigants used in studies on pulpectomies in primary teeth.

Sodium hypochlorite is commonly used in endodontic treatment of permanent teeth. In water, sodium hypochlorite ionizes to Na^+ and OCl^- (hypochlorite ion), which at neutral and acidic pH exists as HOCl (hypochlorous acid). This acid interferes with bacterial metabolism and growth (Haapasalo et al., 2014, Barrette et al., 1989, McKenna and Davies, 1988). Concentrations of between 0.5 -6% are available with 1% sodium hypochlorite most commonly used in primary molars (Ahmed, 2013). It is not only a potent antimicrobial agent but it also dissolves organic necrotic and vital tissue within the root canal system which is of great benefit in primary teeth where it cannot be fully removed mechanically (Haapasalo et al., 2014). The presence of organic material, however, weakens the antimicrobial effect of the hypochlorite so continuous irrigation and time within the canals is required. This may be difficult to achieve in children who do not want to sit in the dental chair for long periods. The disadvantages of sodium hypochlorite, particularly in children, are the unpleasant taste and inflammation and necrosis caused when it comes into contact with vital tissues such as oral mucosa (Chaudhry et al., 2011).

An alternative to sodium hypochlorite is chlorhexidine digluconate which has a more pleasant taste and is less irritant to the tissues. It acts by permeating the microbial cell wall or outer membrane and attacking the inner cell membrane. It also causes tissue coagulation in higher concentrations and binds to hard tissues giving a continued antimicrobial action (Haapasalo et al., 2014). A recent Cochrane review showed little difference between sodium hypochlorite and chlorhexidine irrigations in reducing bacterial cultures but clinically important parameters such as pain and swelling were not recorded in the majority of the studies (Federowic et al., 2012). Louwakul and Prucksathamrongkul (2012) found improved short term success over 6-12 months when 2% chlorhexidine was compared with normal saline solution for pulpectomies in primary molars. However, chlorhexidine does not dissolve organic material like sodium hypochlorite and its antimicrobial action is reduced in the presence of organic matter.

Hypersensitivity to chlorhexidine has become more common since the 1990s as it is incorporated into more and more medical devices as well as being used in antiseptic skin creams and disinfectants (Pemberton and Gibson, 2012, Parkes et al., 2009). Unfortunately two cases of anaphylactic reactions to chlorhexidine mouthwash resulted in fatalities in 2009 and 2011 (Pemberton and Gibson, 2012). Both fatalities were as a result of treatment for infected sockets so the effect of the chlorhexidine contacting an open wound has to be considered as a factor in these reactions. Nevertheless the possibility of an allergic reaction to the irrigant must be considered especially when used without rubber dam isolation.

Antiseptic or antimicrobial pastes used as an intermediate dressing material in a two stage pulpectomy can also be used to pharmacologically clean the root canals. The two most commonly used in the UK are calcium hydroxide paste and Ledermix®, a combination of a corticosteroid (triamcinolone acetate) and a broad-spectrum antibiotic (calcium demethylchlortetracycline). There have been no studies on the use of Ledermix® in non-vital primary teeth. However when used as on cariously exposed canine pulps a combination of Ledermix® and calcium hydroxide showed no difference in inflammation after 7-30 days compared to calcium hydroxide alone (Sazak et al., 1996). Hansen et al. (1971) found that Ledermix® produced less inflammation in the pulp wounds following a vital pulpotomy in primary teeth than zinc oxide eugenol. There was however no difference in inflammation in the apical part of the roots of the teeth. In permanent teeth, Chu et al. (2006) found no significant difference in the number of cultivable microorganisms in root canals following instrumentation, irrigation with 4% chlorhexidine and dressing with an antibiotic and steroid paste or calcium hydroxide paste. Ehrmann et al. (2003) found painful permanent teeth with acute apical periodontitis that had been dressed with Ledermix gave rise to less pain than those dressed with calcium hydroxide or those with no dressing. Ledermix may therefore be more beneficial in dressing the tooth between visits if the tooth is infected as it may help to relieve some postoperative pain as well as pharmacologically cleaning the root canals.

2.3.3 Filling materials

Root canal fillings in primary teeth differ from permanent teeth because the tooth will ultimately resorb and exfoliate and the root canal morphology is very variable. An

ideal root canal filling material for primary teeth should resorb at a rate similar to that of the primary root, be harmless to the periapical tissues and permanent tooth germ, resorb readily if pressed beyond the apex, and be strongly antiseptic. It should easily fill the root canals, adhere to the walls of the canal, not be susceptible to shrinkage, be easily removed if necessary and be radiopaque (Mortazavi and Mesbahi, 2004). Several investigators agree that total removal of the pulp tissue from the root canals of primary teeth cannot be achieved because of their complex and variable morphology (Ballesio et al., 2002, Ahmed, 2013, Gondim et al., 2012). It is also difficult to eliminate the wide range of organisms, which are often present in infected primary root canals. Thus the particular quality of the paste used for filling determines the prognosis in the endodontic treatment of infected primary teeth (Mortazavi and Mesbahi, 2004).

The previous medicament of choice for pulpectomies in primary teeth was slow setting pure zinc oxide eugenol (ZOE) paste. However ZOE is only removed very slowly from the body if extruded through the apex and resorbs more slowly than the tooth so there may be prolonged retention of ZOE and unwanted effects on the permanent successor (Holan and Fuks, 1993, Sadrian and Coll, 1993, Ramar and Mungara, 2010). Coll and Sadrian (1996) found that retention of ZOE after exfoliation or extrusion of ZOE through the apex had no effect on the eruption or formation of the succedaneous tooth. However, those teeth filled short of the apex or completely to the apex had a significantly greater success rate than those filled long i.e. through the apex. The opposite was found by Bawazir and Salama (2006) who had 100% clinical and radiographic success rate in 6 teeth overfilled with ZOE compared with 56% radiographic success and 94% clinical success in underfilled teeth and 92%

clinical and radiographic success in optimally filled teeth. However, the criteria for determining underfilling was that all canals were filled more than 2mm short of the apex and they did not advocate routinely overfilling with ZOE due to the irritant effect on periapical tissues and the slow resorption of extruded material.

Other studies have looked at the use of calcium hydroxide as a root canal medicament. Hendry et al. (1982) found that calcium hydroxide used in the primary teeth of dogs exhibited less inflammation, less resorption and more hard tissue apposition than ZOE treated teeth. However the dogs were only followed up for a maximum of 12 weeks. In vivo studies have found that calcium hydroxide tends to resorb within the root canal at a faster rate than the root resorbs. Despite this Mani et al. (2000) found that calcium hydroxide had a success rate of 86.7% over 6 months compared to 83.3% with ZOE. Ozalp et al. (2005) found that the resorption of calcium hydroxide in the root canals of 4 teeth and subsequent retreatment led to pathological root resorption and extraction of the teeth and they had an 80% success rate compared to 100% with ZOE over 18 months. Rosendahl and Weinert-Grodd (1995) suggest that overfilling with calcium hydroxide and forcing it through the apical foramen may lead to a faster absorption and careful use of working lengths was important.

Recent studies have shown improved success with a mix of calcium hydroxide and iodoform paste (Vitapex®) with a 100% success rate versus 78.5% with ZOE at 16 months following a 2 visit pulpectomy (Mortazavi and Mesbahi, 2004). Ramar and Mungara (2010) found reduced overall success rates for Metapex® – a mix of calcium hydroxide and iodoform compared to a ZOE and iodoform mix and a ZOE,

calcium hydroxide and iodoform mix (Table 1). However they included a faster resorption rate of the filling material compared to the root resorption in their criteria for failure. When looking at success or failure in terms of lack of pain and healing periapical or furcation lesions Metapex® had 100% success rates compared with ZOE and iodoform which had 97% clinical success and 90.6% radiographic success. This agrees with the results from Subramaniam and Gilhotra (2011). Ozalp et al. (2005) also found that Vitapex® had a similar success to ZOE when used for one visit pulpectomies and was more quickly resorbed when canals were overfilled. Mortazavi and Mesbahi (2004) also found that Vitapex® is more easily eliminated by the body. Ozalp et al. (2005) did find that 30% of Vitapex® filled teeth showed complete resorption of the filling material from the canals but there were no clinical or radiographic signs of treatment failure.

The updated Cochrane review of pulp treatments for extensive decay in primary teeth provided a systematic review of more papers than the previous review but still found insufficient evidence of the superiority of one medicament for filling the root canals of necrotic primary teeth. Most studies compared 2 different medicaments and there was significant heterogeneity of techniques, irrigants and restoration of the tooth (Smail-Faugeron et al., 2014).

2.3.4 Adverse effects

The most important adverse effect of pulp treatments would be failure to control infection in the non-vital tooth, leading to pain, swelling and the need for further

treatment. However, even when pulp treatment is successful it can cause problems with the permanent successor. Early studies suggested an increased incidence of enamel defects in successors following pulp treatment in the primary tooth (Pruhs et al., 1977, Messer et al., 1980). However, both Mulder et al. (1987) and Coll and Sadrian (1996) found no significant difference in enamel defects compared with the contralateral non-pulpectomised tooth and no relationship with the retention of zinc oxide eugenol or the length of the filling. In fact the risk of enamel defects was associated more with the degree of root resorption in the primary tooth and could therefore be related to the extent of infection pre-operatively (Coll and Sadrian, 1996). This contradicts Macko et al who found no relationship between primary molars with extensive caries and enamel defects in premolars but they looked at primary molars and radiographic results only whereas Coll and Sadrian treated both anterior and posterior teeth and investigated clinically and radiographically (Macko et al., 1979, Coll and Sadrian, 1996).

Several studies have suggested that pulp treatments may affect the eruption of the permanent successor, particularly when filling material is extruded through the apex. Coll and Sadrian (1996) found that ZOE was often retained in the periapical tissue even after exfoliation of the primary molar and it is thought this may result in abnormal eruption for the permanent successor. Deflection from the normal path of eruption was seen in 2 out of 19 patients treated with ZOE by Mortazavi and Mesbahi (2004) and 4 out of 100 ZOE and 2 out of 100 Vitapex® filled teeth by Trairatvorakul and Chunlasikaiwan (2008). Deflection was slightly more frequent in teeth with long root fillings and in the case of the short filled Vitapex® tooth was actually related to a large furcation radiolucency (Trairatvorakul and Chunlasikaiwan, 2008). This could

have been indicative of cystic change. Other studies suggest that necrotic tissue in the root canals in addition to the phenol group in pulp therapy medicaments used in the past may result in radicular cysts which grow rapidly in size and can displace the permanent successor (Savage et al., 1986). This is supported by results from Hill (1978) and Mass et al. (1995) who found that all the radicular cysts they examined were associated with severely decayed primary teeth and only 4 out of 36 teeth had previous pulp therapy. Similar results were found for a primary molar treated with a mixture of calcium hydroxide and iodoform in a case report published by Takiguchi et al. (2001).

The most common adverse effect seen subsequent to pulp treatments is advanced root resorption and premature exfoliation of the primary molar. This was originally thought to be due to formocresol stimulating a chronic inflammatory action in the periapical tissues as it was found in several studies where formocresol was used (Barr et al., 1991, Morawa et al., 1975, Fuks and Bimstein, 1981, Wright and Widmer, 1979). However, Coll and Sadrian (1996) found that although 52.7% of pulpectomised molars filled with zinc oxide eugenol exfoliated at the normal time, 43.2% exfoliated more than 6 months early whilst only 4.1% exfoliated more than 6 months later than normal. This suggests that the inflammation within the necrotic root canal spreads to the periapical area and accelerates physiological root resorption. This theory is supported by similar results from Trairatvorakul and Chunlasikaiwan (2008) for both zinc oxide eugenol and Vitapex® pulpotomies. Further research by Moskovitz et al. (2012) showed significantly higher root resorption in endodontically treated primary molars filled with a paste containing iodoform, zinc oxide and calcium hydroxide compared with their homologous teeth. They suggest this may be the

result of infection in the periradicular tissues stimulating the formation of odontoclasts. Ballesio et al. (2002) found no alteration in physiologic resorption and normal exfoliation when non-vital teeth were pharmacologically and chemically treated with copious irrigation with 10 vol hydrogen peroxide and 3% sodium hypochlorite and dressed with powdered macrolide antibiotic and glycerine for 8-10 days, followed by filling with a mix of powdered antibiotic, glycerine and zinc oxide eugenol. This regime may therefore reduce the inflammation and infection sufficiently to prevent the stimulation of osteoclasts.

2.3.5 Restoration of the coronal portion

Restoration of the coronal portion of the tooth following pulp treatment will depend on the extent of the caries, the material used for obturating the root canals and the child's cooperation. Options include intracoronal restorations such as composite or amalgam or extracoronal preformed metal crowns. Some studies used zinc-oxide eugenol paste for the coronal restoration (see Table 1) but found the success rate of pulpectomies significantly reduced from 95% to 28.6% and failure was associated with the loss of zinc-oxide eugenol restorations (Moskovitz et al., 2005, Thomas et al., 1994). Moskovitz et al. (2005) is the only study to directly compare the success rates of different coronal restorations, the majority (70.5%) were restored with stainless steel crowns and these were marginally more successful than those restored with amalgam or composite (95.9% successful compared to 92.3%). Table 1 demonstrates similar success rates for all types of restoration and does not suggest any advantage of immediate placement of a preformed metal crown over waiting a few weeks after the pulp treatment. However, delaying the placement of the

preformed metal crown provides more opportunity for loss of the interim restoration which Thomas et al. (1994) found was the main reason for failure of pulp treatments.

2.4 Summary

The anatomy and physiology of primary molars is such that interproximal caries is more likely to go undetected and may lead to pulpal inflammation at an earlier stage. Pulp inflammation may not always be effectively managed by general dental practitioners leading to pulpal necrosis and infection. At this stage the management of non-vital or infected molars is complicated by the anatomy of the molar, physiological resorption of the root and patient management. The current gold standard for management according to BSPD guidelines is pulpectomy or extraction. However not all children may tolerate a pulpectomy and there is evidence to suggest that pulpotomies may be just as effective. Formocresol was previously used for pulpotomies but has since been registered as carcinogenic by the IARC so its use has been restricted.

The success of pulpectomies, and therefore pulpotomies, depends upon managing infection with the medicaments used for irrigation, obturation and intermediate dressing as well as the technique used for cleaning the root canals and the length of root filling or calculation of working length. Shorter root fillings with calcium hydroxide and iodoform appear to have the best success rates (up to 100%). Sodium hypochlorite is the best irrigant for dissolving organic material and disinfecting the root canal but has issues of poor taste, irritation of the soft tissues and length of time required for it to be in the root canal. Chlorhexidine digluconate may therefore be a more appropriate irrigant in children with limited cooperation.

Coronal restoration with a preformed metal crown has also been shown to improve the success rate of pulp treatments in primary molars.

CHAPTER 3: AIMS AND OBJECTIVES

Aims

To assess the clinical and radiographic outcome of a 'non-root canal instrumentation/Scottish pulpotomy' compared with a pulpectomy involving root canal instrumentation for non-vital primary molars.

Objectives

1. To assess the long term survival of primary molars treated by either method and determine any difference in effect size
2. To investigate clinically and radiographically resolution of infection and symptoms
3. To record any complications occurring from either technique
4. To assess the feasibility of patient recruitment, cooperation with treatment and return for follow-up appointments

CHAPTER 4: MATERIALS AND METHODS

4.1 Introduction

The aim of this study was to investigate the effectiveness of a non-root canal instrumentation/Scottish pulpotomy in comparison to the gold standard root canal instrumentation pulpectomy in the management of non-vital primary molars. As there is little evidence on the success of non-vital pulpotomies using current root canal medicaments, a pilot randomised clinical trial was designed to determine the size of the differences in clinical and radiographic outcomes between the two techniques. The pilot design also aimed to collect data on the feasibility of conducting a larger scale randomised controlled trial to provide a stronger evidence base for the use of the simpler technique described in the SDCEP guidelines (Scottish Dental Clinical Effectiveness Programme (SDCEP), 2010).

4.2 Study design

The study was designed as a pilot randomised controlled trial to compare a pulpectomy under rubber dam isolation and local anaesthetic with a pulpotomy (where the root canals are not instrumented) under the same conditions. The same materials were used for irrigation, root filling and coronal restoration so the only difference between the groups was the instrumentation of the root canals.

It was appreciated that some children would not be able to cooperate for the standardised conditions of the interventions in the randomised arms of the trial so a pragmatic treatment group was developed. The pragmatic group received the treatment that would normally be provided for less cooperative children but could not

be directly compared to the gold standard pulpectomy treatment as the conditions were not standardised and the teeth were not randomly allocated to this group.

4.3 Ethical approval

The research protocol and patient and parent information sheets were approved by the Local Research Ethics Committee before the study commenced (Appendix 1). The local National Institute for Health Research Comprehensive Local Research Network (NIHR CLRN) also granted permission to undertake treatment on National Health Service (NHS) patients in NHS clinics (Appendix 2).

4.4 Recruitment of subjects

Subjects were primary molars with clinical and/or radiographic signs of loss of pulp vitality in healthy children aged 4-9 years. The inclusion and exclusion criteria are shown in Table 2, these were based on inclusion and exclusion criteria used in previous studies on pulp treatments in non-vital primary teeth. Children with systemic disease were excluded due to the risks of leaving a possible source of infection within the root canals in these children. Teeth with extensive root resorption were excluded as Coll and Sadrian (1996) found that the amount of preoperative root resorption was the most important determinant of the success of a pulpectomy and root resorption of more than two thirds root length may result in early exfoliation, potentially before the follow-up period is complete.

Inclusion criteria

- Primary molar with signs or symptoms of loss of vitality (i.e. continuous or spontaneous pain, buccal swelling and/or sinus, mobility, bifurcation or periapical radiolucency, pathological root resorption, persistent haemorrhage, necrotic tissue or suppuration on accessing pulp chamber)
- Child aged 4-9 years old
- No systemic disease

Exclusion criteria

- Unrestorable molars
- Children with systemic disease
- Facial cellulitis or significant extraoral swelling
- Internal pathological root resorption
- Inadequate bone support or less than two thirds root length due to physiological or external pathological root resorption
- Child requires GA for extraction of other grossly carious teeth

Table 2: Inclusion and exclusion criteria

Potential subjects were identified from the referral letters for children placed on the 'Anxious child' waiting list at a community dental clinic in West Bromwich. The children were invited to attend a new patient assessment at the community dental clinic at the Lyng Health Centre or were identified at their new patient assessment at Birmingham Dental Hospital. A clinical and medical history was undertaken followed by a thorough clinical and radiographic examination of any primary molars requiring

pulp treatment. Radiographic examination was by long cone periapical or vertical bitewing radiographs taken using size 0 films in a standard Rinn® film holder to enable reproducible and comparable radiographs over time. If the children were not able to tolerate the film holder bitewing tabs were used with the same size films. The film was centred over the non-vital primary molar but positioned to obtain as much diagnostic information from the radiograph as possible in particular caries in other teeth.

A treatment plan was then formulated and the treatment options discussed with the patient and parent or guardian. If they were happy to proceed with restoration of the non-vital primary molar rather than extraction and fulfilled the inclusion criteria, then both verbal and written information was given about the research project (Appendix 3 and 4) and informed consent was obtained from the parent or guardian for inclusion in the study (Appendix 5). They were then given an appointment for the pulp treatment.

4.5 Location

The subjects were recruited from the West Midlands, where 26% of 5 year olds had evidence of caries and the mean $d_3$mft was 0.82 in 2011/12 although the water is fluoridated (Davies et al., 2012). There is also a high level of deprivation with a large percentage of immigrants and ethnic minorities and the third largest proportion of foreign born residents in the UK (11.8%) (Office for National Statistics, 2011).

The paediatric department at Birmingham Dental Hospital receives 2000 referrals a year from across the West Midlands so it provided a large population of patients but referrals for management of dental caries are often sent straight out to

community dental clinics. It was therefore unlikely that sufficient numbers would be recruited from the dental hospital alone. The community dental clinic at West Bromwich was chosen because West Bromwich is within Sandwell local authority which has the 17th highest proportion of deprived areas in England, Birmingham has the 9th highest (Department for communities and local government, 2010). This suggested that the level of caries in Sandwell may be higher than the $d_3$mft of 0.84 suggested in the NHS Dental Epidemiology Programme 2011/2012 survey of 5 year olds (Davies et al., 2012). This result may be due to the need for positive consent and the reduced number of English speakers in areas of high immigration such as Sandwell. The care index of 9.6% in Sandwell was also low compared with a national average of 11.2% and 1.4% of 5 year olds in Sandwell had evidence of an abscess or sepsis so it was felt there may be a high proportion of younger children with non-vital primary molars requiring restoration in this area (Davies et al., 2012).

4.6 Sample size

Subjects were primary molars with clinical and/or radiographic signs of loss of pulp vitality in healthy children. At the time the study was set up there was no available evidence on the efficacy of pulpotomy treatments in non-vital primary molars without formocresol. The efficacy of pulpectomies with iodoform and calcium hydroxide paste was between 89%-100% (Mortazavi and Mesbahi, 2004, Trairatvorakul and Chunlasikaiwan, 2008, Ozalp et al., 2005). Following discussion with a statistician it was therefore decided to carry out a pilot study to obtain baseline data on the success rates of pulpotomy versus pulpectomy and the degree of difference in success rates as well as the feasibility of recruitment and follow-up of the participants. Therefore, the sample size was set at 30 molars in each arm of the

randomised section of the study, i.e. 30 pulpectomies, 30 pulpotomies, which would be enough to detect some difference and would allow for the possibility of loss to follow-up. Previous studies have shown no statistical difference in success rates between first or second and maxillary or mandibular primary molars so randomisation was applied to all teeth rather than by tooth type (Ozalp et al., 2005). The size of the pragmatic treatment group was dependent on the number of uncooperative children recruited before 60 were recruited for the randomised trial. It was estimated that 40% of children meeting the inclusion criteria would be uncooperative, making a pragmatic group size of 40 teeth and total study size of 100 teeth.

4.7 Allocation to groups (Randomisation)

At the pulp treatment appointment the cooperation of the child was assessed by their ability to tolerate placement of a local anaesthetic infiltration and a rubber dam over the non-vital primary molar. If their cooperation was sufficient the tooth was randomly allocated to either the pulpectomy or pulpotomy group by block randomisation with a block size of 4 by placing cards stating A or B in sealed opaque envelopes distributed to each site. Card A indicated pulpectomy treatment and B indicated pulpotomy treatment. Any child with more than one non-vital primary molar meeting the inclusion criteria had the technique for the first tooth randomly assigned and subsequent molars treated by the other technique. If the child was uncooperative they were allocated to the pragmatic treatment group. Appendix 6 shows the study flow chart which illustrates the allocation of subjects to each group.

4.8 Treatment protocol

Once the tooth was allocated to a group the treatment was carried out as detailed below.

a) Pulpectomy group

Following local anaesthetic infiltration and rubber dam placement, dental caries was removed and the pulp chamber fully unroofed with a safe ended bur (Figure 4b and 5b & c). The root canal orifices were identified and irrigated with chlorhexidine solution (0.2%). The working length of the root canals was estimated using the preoperative radiographs and small hand files (no greater than size 30) were inserted into the canals to 2mm short of the estimated apex (Figure 4b and 5c). The canal walls were lightly filed to remove all necrotic pulp tissue but without removing dentine from the canal walls. The pulp chamber and canals were irrigated with chlorhexidine again and the root canals dried with paper points to 2mm from apices (Figure 4d & e and 5e & f). If the canals were clean and dry the tooth was obturated with calcium hydroxide and iodoform paste (Vitapex®, Neo Dental international, Federal Way/WA, USA) using the supplied syringe and disposable tips to 2 mm short of the apices (Figure 4f and 5g). The pulp chamber and cavity were then filled with zinc oxide eugenol paste (IRM®, Dentsply, Caulk, Milford) and the molar was restored with a preformed metal crown (3M ESPE, St Paul, Minnesota) at the same visit (Figure 4g & h and 5h & i). If infection was present then the root canals and pulp chamber were dressed with Ledermix® (Dentsply, Milford) on a cotton wool pellet and IRM®. The patient returned within 2 weeks to complete the pulpectomy and restore with a preformed metal crown as above.

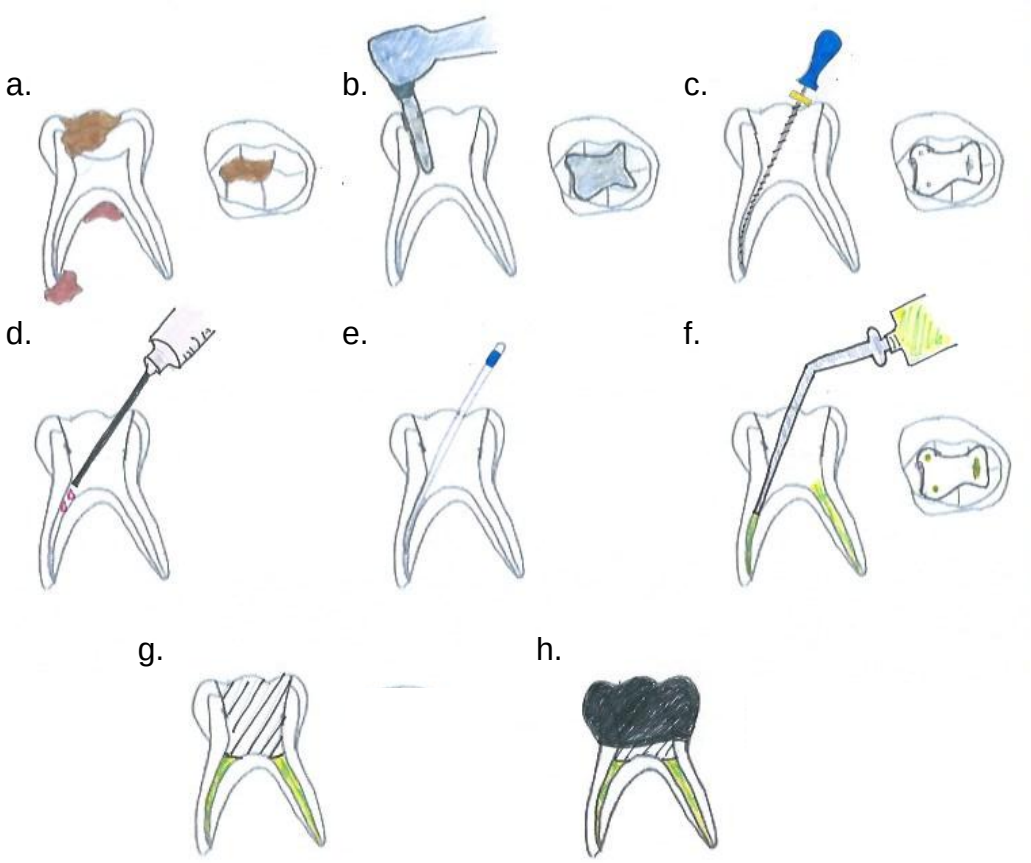
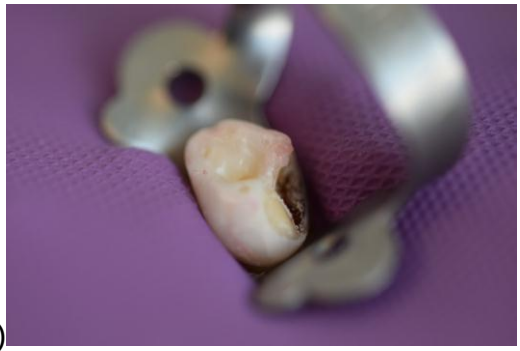


Figure 4: Pulpectomy technique a. Caries in primary molar b. Unroofing pulp chamber filing root canals to 2mm of apex d. Irrigation with chlorhexidine e. Drying root canals with paper points f. Filling root canals with Vitapex® to 2mm from working length g. Filling access cavity with IRM h. Coronal restoration with preformed metal crown

a) 

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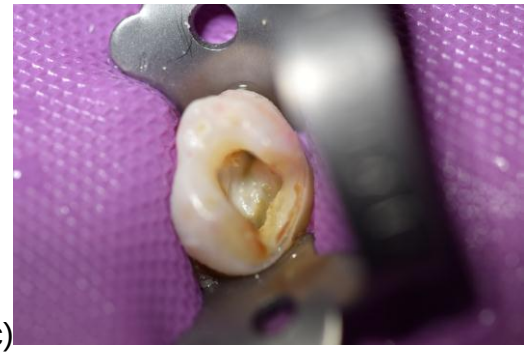
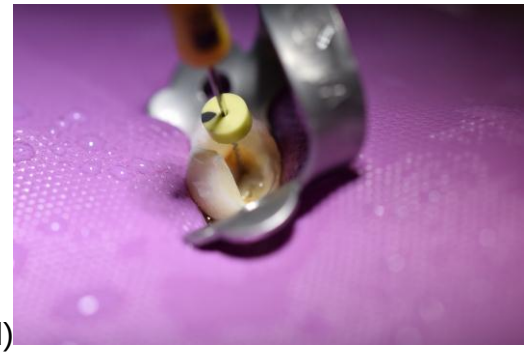
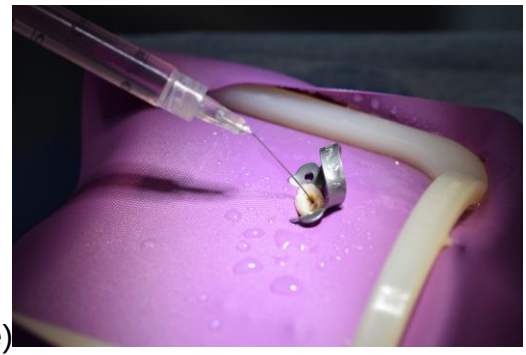
c) 

d) 

e) 

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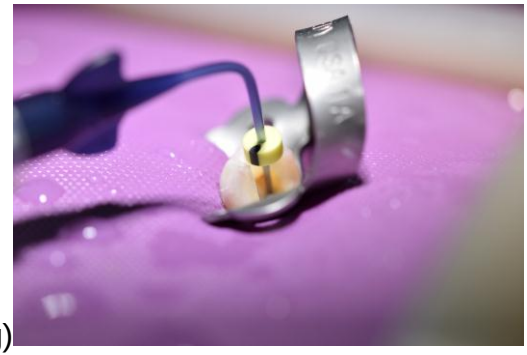
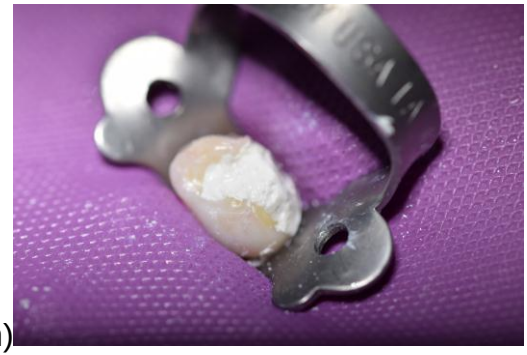
g) 

h) 

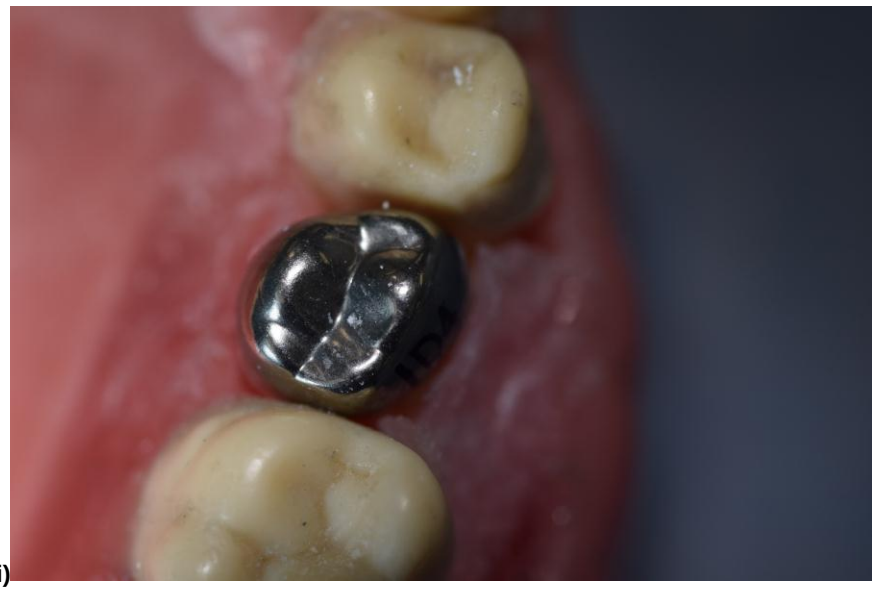
i) 

Figure 5: Pulpectomy technique a. Caries in primary molar b & c Unroofing pulp chamber filing root canals to 2mm of apex e. Irrigation with chlorhexidine f. Drying root canals with paper points g. Filling root canals with Vitapex® to 2mm from working length h. Filling access cavity with IRM i. Coronal restoration with preformed metal crown

b) Non-root canal instrumentation/Scottish pulpotomy group

As for the pulpectomy group, local anaesthetic infiltration was given and rubber dam placed, followed by dental caries removal and unroofing of the pulp chamber using a non-end cutting bur (Figure 6b and 7b & c). Once necrotic tissue had been removed from the pulp chamber with a sharp excavator or rosehead stainless steel bur and the chamber was irrigated with chlorhexidine solution (0.2%) and the root canal entrances identified. Necrotic tissue visible in the canal entrances was removed with a sharp probe but no files were used in the root canals (Figure 6c and 7d). Following further irrigation with chlorhexidine the pulp chamber was dried with cotton wool and Vitapex® injected into the coronal section of the root canals using the

supplied syringe and disposable tips (Figure 6 d, e & f and 7e, f & g). The pulp chamber was then back filled with IRM® with firm pressure and the tooth restored with a preformed metal crown at the same visit (Figure 6 g & h and 7 h & i). The firm pressure was important to ensure that Vitapex® is forced as far down the necrotic root canals as possible. As above, if infection was present the pulp chamber was dressed with Ledermix®, a cotton wool pellet and IRM® for 2 weeks.

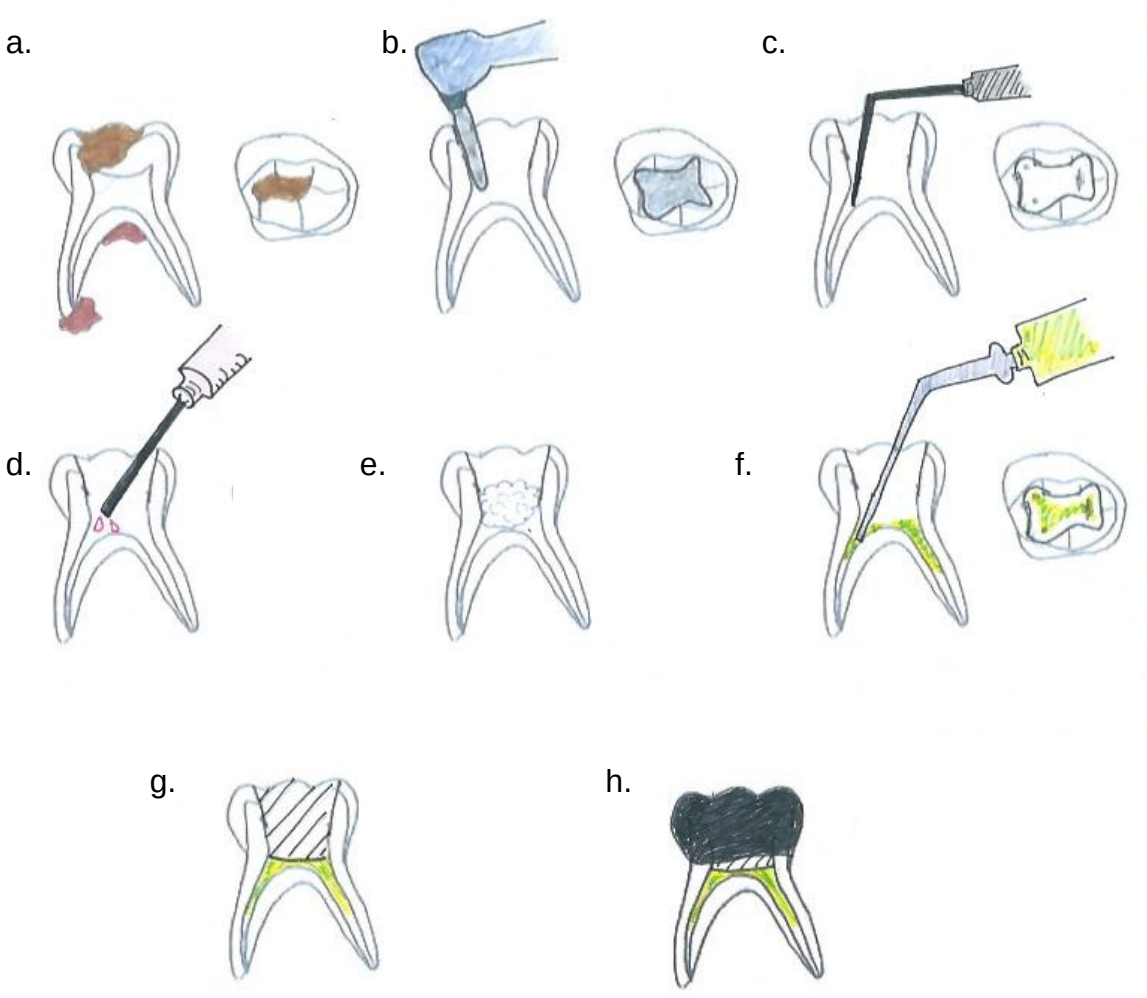
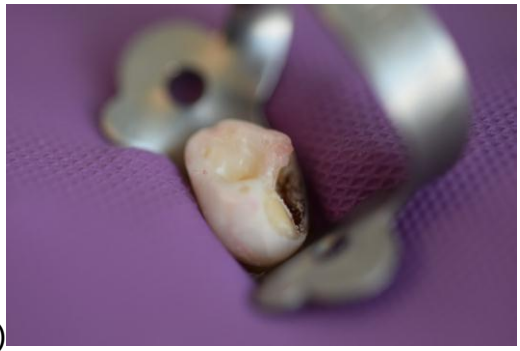


Figure 6. Pulpotomy technique a. Caries in primary molar b. Unroofing pulp chamber c. Probing root canal orifices d. Irrigation with chlorhexidine e. Drying with cotton wool pellet f. Placing Vitapex® over root canal orifices g. Filling access cavity with IRM h. Coronal restoration with preformed metal crown

a) 

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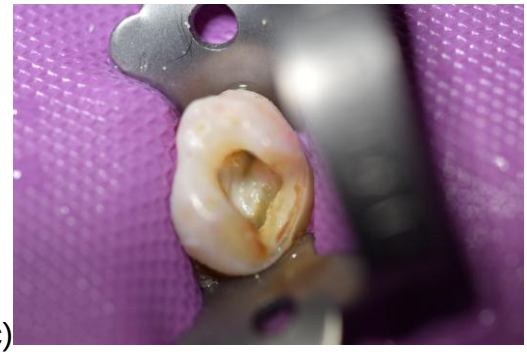
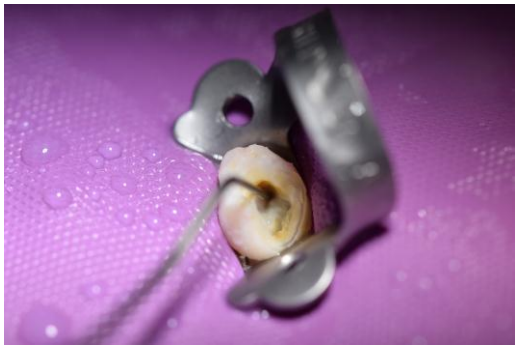
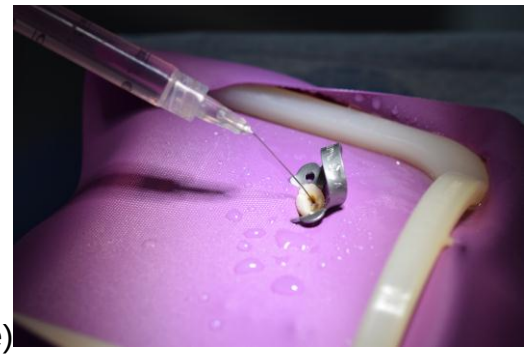
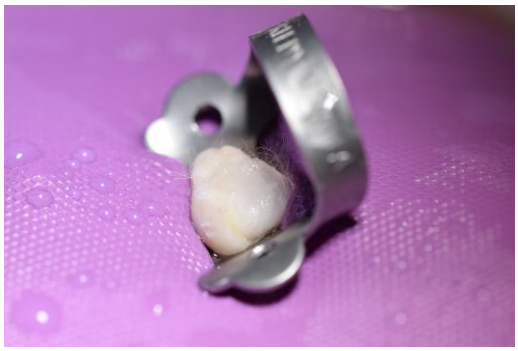
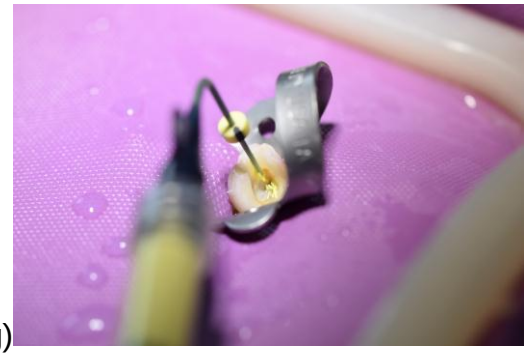
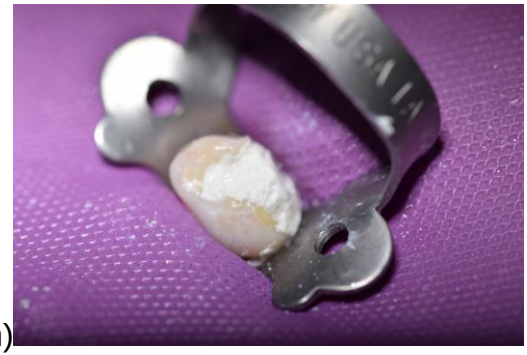
c) 

d) 

e) 

f) 

g) 

h) 

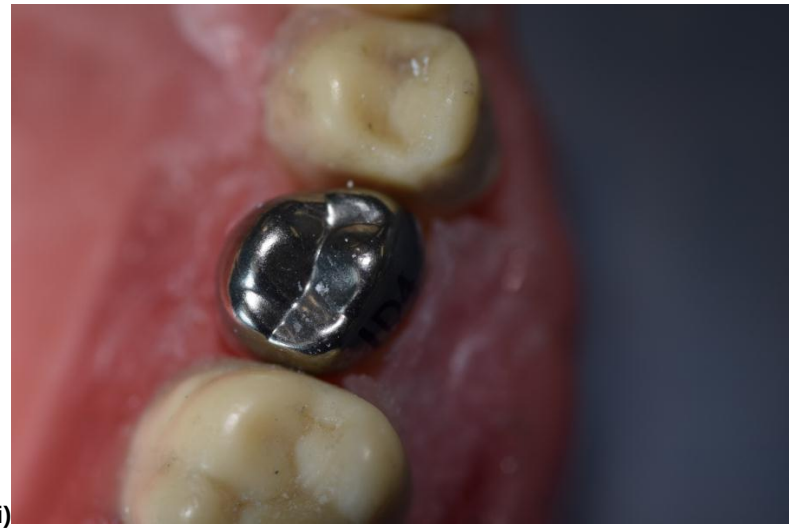
i) 

Figure 7: Pulpotomy technique a. Caries in primary molar b & c. Unroofing pulp chamber d.Probing root canal orifices e. Irrigation with chlorhexidine f. Drying with cotton wool pellet g. Placing Vitapex® over root canal orifices h. Filling access cavity with IRM i. Coronal restoration with preformed metal crown

c) Pragmatic treatment group

Children who were assessed as insufficiently cooperative to have a pulpectomy treatment because they could not tolerate local anaesthetic placement and/or rubber dam isolation were not randomised but where possible had a pulpotomy treatment as described in SDCEP guidelines (Scottish Dental Clinical Effectiveness Programme (SDCEP), 2010). This was the same technique as the non-root canal instrumentation/ Scottish pulpotomy group, as shown in figures 6 and 7 but without local anaesthetic infiltration and/or rubber dam isolation. The pulp chamber was accessed as before and the root canal orifices probed with a sharp probe. The pulp chamber was then irrigated with chlorhexidine 0.2% and dried with cotton wool. The coronal section of the canals was filled with Vitapex® and the pulp chamber with IRM® before restoring with a preformed metal crown.

All treatments were carried out by the same operator (JM) at either Birmingham Dental Hospital or the community dental clinic at the Lyng Health Centre, West Bromwich between June 2012 and June 2013.

4.9 Review and outcome measures

Following the pulp treatment, the subjects were reviewed clinically and radiographically every 6 months for 2 years by a speciality registrar (JM) or consultant in Paediatric Dentistry. The primary outcome measure was the clinical success of the pulp treatment defined as the absence of all of the clinical signs of infection (Table 3) at 6 month review.

Clinical criteria:

1. Gingival swelling or sinus tract.
2. Purulent exudate expressed from gingival margin.
3. Abnormal mobility other than mobility from normal exfoliation.
4. Pain on postoperative check-up.

Radiographic criteria:

1. Pathological signs of external root resorption or continued resorption if any was present preoperatively.
2. No resolution of a bifurcation radiolucency 12 months postoperatively.
3. Periradicular or furcation radiolucency formation postoperatively.

Table 3: Clinical and radiographic signs of infection (failure) postoperatively

All subjects had a radiograph taken immediately postoperatively to assess the adequacy of the endodontic filling and to provide a baseline radiograph. The post-operative and follow-up radiographs were taken with a size 0 film and standard Rinn

holder where possible, using the same technique as the pre-operative radiograph to allow reliable comparisons over time. Consideration was also given to ensuring the maximum diagnostic yield from the radiographs by ensuring that they could diagnose caries in adjacent teeth also.

Digital photographs were taken of all radiographs using a Nikon D5300 digital SLR camera and Sigma 105mm f/2.8 macro lens. The radiographs were assessed on a computer monitor by an independent paediatric dentist who was blinded to the treatment groups. The root fillings were categorised as a short fill (all canals are filled 3mm or more short of the apex), a complete fill (one or more of the canals having Vitapex® within 2mm of the radiographic apex) or a long fill (any canal showing Vitapex® outside of the root). This was entered onto a case report form (Appendix 7). The radiographs taken at the 6 month follow-up appointments were reassessed one month later and an intra-examiner agreement coefficient was calculated to determine the reliability of the radiograph assessment.

The secondary outcome measures were clinical and radiographic success of the pulp treatment at 6 month follow-up and over long term follow-up (2 years). The radiographic measure of success was defined as the absence of all of the radiographic signs of infection (Table 2). The combination of clinical and radiographic features recorded in Table 3 includes all of the 5 component outcomes forming a composite outcome of failure of a pulp treatment: soft-tissue pathology, pain, pathologic mobility, pathologic radiolucency and pathologic root resorption as developed by Smaïl-Faugeron et al. (2013).

Secondary outcome measures also included the children's rating of each technique. They were asked by a dental nurse to indicate how they felt about the treatment immediately post-operatively using the Wong-Baker FACES scale (Appendix 8). The number of the face was then recorded on a case report form (Appendix 7) along with data about the clinical signs and symptoms and radiographic appearance immediately postoperatively. The same forms were completed at each review appointment to enable easy comparison.

Finally, information was also collected regarding the recruitment clinics at the Lyng Health Centre, in particular the number of patients suitable for the study from referral letters, the number seen in clinics, the number recruited and treatment completed. The number of patients lost to follow up at each review appointment was also recorded.

4.10 Data analysis

The data including screening clinic and recruitment data as well as study subject data was added to a Microsoft Excel® spreadsheet. The percentage of patients recruited from the screening clinics was calculated as well as any differences between the recruits and non-recruits. The clinical and radiographic outcomes were analysed by an independent statistician to compare the differences between success rates in the 3 groups. The null hypothesis that there was no difference between the groups was tested by comparing the percentage success rate in the pulpotomy group, the pragmatic treatment group and the pulpectomy group to each other using descriptive statistical analysis.

The children's experience of each treatment was analysed by comparing the percentage of positive feelings (Wong-Baker FACES scale 0 and 1) to the percentage of negative feelings (Wong-Baker FACES scale 4 and 5) in each treatment group.

4.11 Summary

A pilot randomised controlled trial was undertaken to compare the success of a pulpectomy versus a pulpotomy in non-vital primary molars in fit and healthy children age 4-9 years old. The treatment was standardised between the 2 groups except for the insertion of an endodontic file in the root canals of the pulpectomy group. A pragmatic treatment group had the same treatment as the pulpotomy group but without rubber dam isolation and/or local anaesthetic due to reduced cooperation. The clinical and radiographic success was assessed at 6 monthly intervals over a 2 year period. The children were also asked to rate their experience of the treatment and data was collected on the recruitment of subjects for the study and loss to follow-up.

CHAPTER 5: RESULTS

5.1 Recruitment of subjects

In total, 4 children with 4 non-vital primary molars were recruited from Birmingham Dental Hospital and 11 children with 18 primary molars from the Lyng Health Centre. At the Lyng Health Centre 109 children were assessed as suitable for the study on the basis of their referral letters, 35 children (32.1%) were not brought to their assessment appointments and 12 (11.0%) cancelled their assessment appointment. Of the remaining 62 children, 51 (46.7%) were unsuitable for the study. The overall recruitment rate at the Lyng Health Centre was therefore 10.1% from referral letters and 17.7% from attendance in clinic. This is shown in Figure 8.

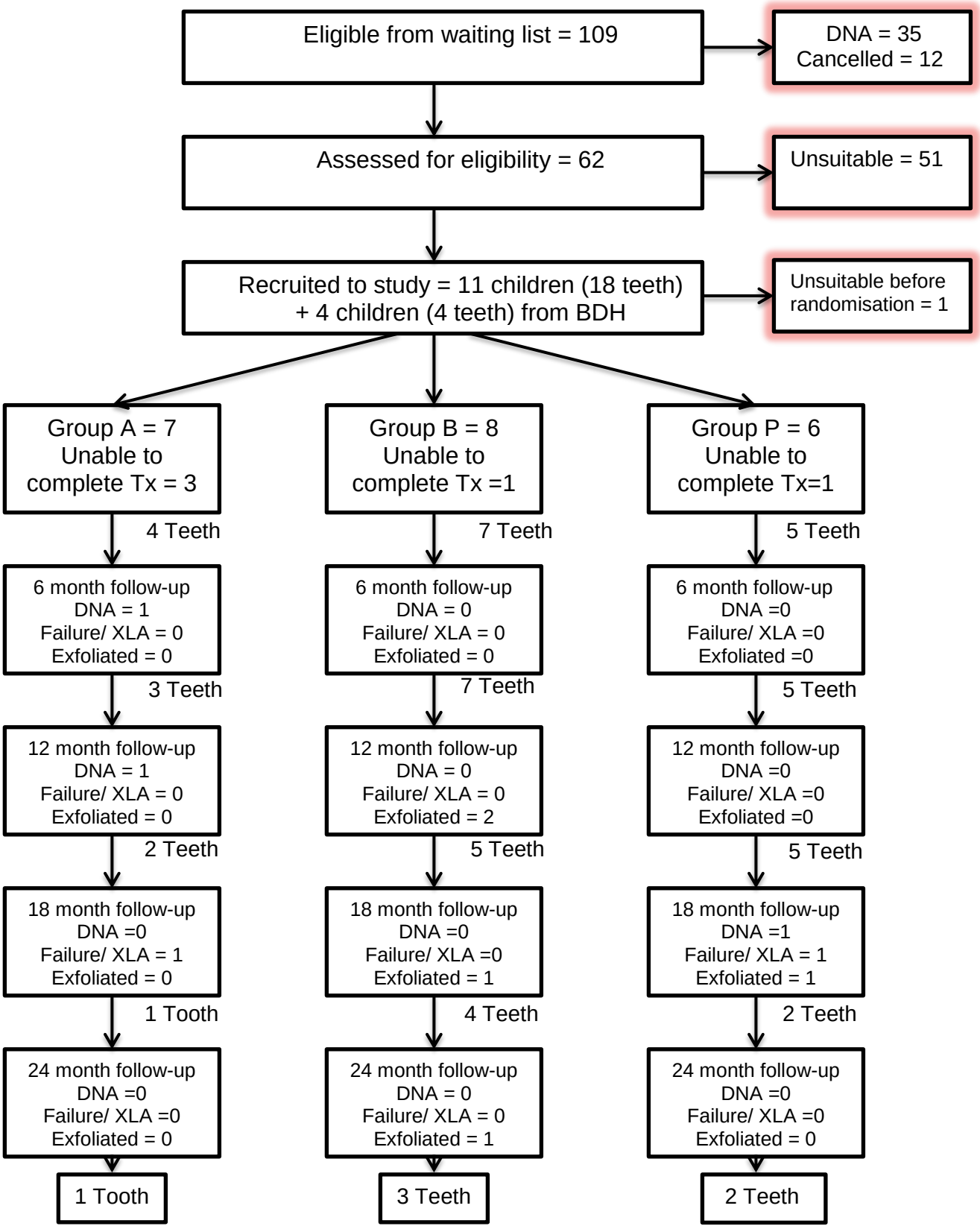


Figure 8: CONSORT flow diagram where group A = pulpectomy group, B = pulpotomy and group, P = pragmatic treatment, DNA = did not attend, Tx = treatment, XLA = extraction

The reasons for children at the Lyng being unsuitable for inclusion are shown in Table 4 with the most common reasons being that the child had no non-vital teeth on examination (31.4%) and the child's cooperation was not sufficient to carry out the treatment (25.5%). An inability to take preoperative radiographs due to poor cooperation was also a problem in 5 children (9.8%). Three children (5.9%) were too old to participate, they were assessed by mistake as they had primary caries noted on the referral letter or they were booked in with the speciality registrar for assessment of another dental problem.

	No of patients n (%)
No non-vital teeth	16 (31.4%)
Pt cooperation insufficient	13 (25.5%)
Uncooperative for radiographs	5 (9.8%)
Tooth unrestorable	5 (9.8%)
Too old	3 (5.9%)
Pt declined to participate	2(3.9%)
Medical history	2(3.9%)
Failed to attend further appointments	2(3.9%)
Frequent infections	1 (2.0%)
Root resorption >2/3	1 (2.0%)
Multiple non-vital carious teeth	1 (2.0%)
	51

Table 4: Reasons for non-inclusion in study

5.2 Demographics of subjects

All children included in the study were in the age range 5-9 years old with the majority (46.7%) aged 6 years old. The children who were unsuitable covered a much broader age range 3-14 years old for reasons stated above with the majority in the younger range 3-6 years old. There were approximately equal males and females in those assessed as unsuitable but the majority of those included in the study were male (80%) (Table 5).

White British was the predominant ethnicity for both included and excluded subjects with Asian being the second most common but a range of ethnicities were assessed and included in the study (Table 5).

		Unsuitable n(%)	Study n(%)
Age	3	3 (5.8%)	0 (0%)
	4	10 (19.6%)	0 (0%)
	5	10 (19.6%)	2 (13.3%)
	6	10 (19.6%)	7 (46.7%)
	7	7 (13.7%)	4 (26.7%)
	8	5 (9.8%)	1 (6.7%)
	9	3 (5.8%)	1 (6.7%)
	10	0 (0%)	0 (0%)
	11	0 (0%)	0 (0%)
	12	0 (0%)	0 (0%)
	13	2 (3.9%)	0 (0%)
	14	1 (2.0%)	0 (0%)
Gender	Male	26 (51.0%)	12 (80.0%)
	Female	25 (49.0%)	3 (20.0%)
Ethnicity	White - British	18 (35.3%)	8 (53.3%)
	Other white	9 (17.6%)	1(6.7%)
	Asian	12 (23.5%)	4 (26.7%)
	Mixed - Asian + white	1 (2.0%)	0 (0%)
	Mixed - black + white	2 (3.9%)	1 (6.7%)
	Other ethnicity	1 (2.0%)	0 (0%)
	Unknown	8 (15.7%)	1 (6.7%)

Table 5: Demographics of subjects excluded and included in study

The demographics of the groups after randomisation can be seen in Table 6. The mean ages are all similar but there was a slightly older age range in the pulpotomy group. All three groups had a greater proportion of boys with slightly more girls in the pulpotomy group. There was an even spread of maxillary, mandibular, first and second molars between the groups, although there were fractionally more mandibular molars in the pragmatic group perhaps indicating rubber dam placement

was more difficult in the mandible. With regard to the baseline characteristics of the groups all teeth in the pragmatic group were causing pain, whilst 75% of those in the pulpotomy group and 57.1% of the pulpectomy group had pain. A higher number of teeth in the pulpotomy group (62.5%) had a swelling and sinus, compared with only 1 tooth in the pulpectomy group. Radiographically, at baseline 3 teeth in the pulpectomy group (42.9%), 3 teeth in the pulpotomy group (37.5%) and 2 teeth in the pragmatic treatment group (33.3%) had a bifurcation radiolucency. Finally, 66.7% of teeth in the pragmatic group required an interim Ledermix® dressing compared with 57.1% in the pulpectomy group and only 37.5% of the pulpotomy group.

	Pulpectomy	**Pulpotomy**	**Pragmatic**
Age (mean, range)	6.3(5-7)	6.75(5-9)	6.2(5-7)
Gender Male n(%)	6 (85.7%)	6 (75%)	5 (83.3%)
Maxillary molars	4	5	2
Mandibular molars	3	3	4
First primary molars	3	4	3
Second primary molars	4	4	3
Pain	4 (57.1%)	6 (75%)	6 (100%)
Swelling	1 (14.3%)	5 (62.5%)	3 (50%)
Sinus	1 (14.3%)	5 (62.5%)	2 (33.3%)
Exudate	0 (0%)	1 (12.5%)	0 (0%)
Mobility	0 (0%)	4 (50%)	2 (33.3%)
Bifurcation radiolucency	3 (42.9%)	3 (37.5%)	2 (33.3%)
Periapical radiolucency	1 (14.3%)	0 (0%)	1 (16.7%)
Pathological root resorption	0 (0%)	0 (0%)	0 (0%)
Ledermix® dressing	4 (57.1%)	3 (37.5%)	4 (66.7%)

Table 6: Demographics of the groups after randomisation

For 4 out of the 6 teeth in the pragmatic treatment group the children cooperated for local anaesthetic infiltration but none cooperated for rubber dam placement. All

were cooperative enough to complete treatment but one had a pulp floor perforation and the tooth was therefore extracted.

5.3 Retention of subjects

As the CONSORT flow diagram in Figure 8 shows, only 6 teeth from the original 22 teeth recruited completed the study to 24 months - a completion rate of 27.3%. Treatment could not be completed in 5 teeth. One tooth in the pulpectomy group was found to be vital on accessing the pulp chamber, the pulp chamber floor was perforated in another tooth (pragmatic group) and 3 children were not cooperative enough to complete the treatment (2 from pulpectomy group and 1 from pulpotomy group). Two teeth had exfoliated at 12 months, 2 at 18 months and 1 at 24 months. Two teeth were extracted due to failure of the pulp treatment at 18 months (pulpectomy and pragmatic group). One child did not return for follow-up after 6 months, 1 after 12 months and 1 after 18 months. The retention rate of those who entered follow-up was therefore 13 teeth out of 16 (81.3%).

5.4 Patient satisfaction with treatments

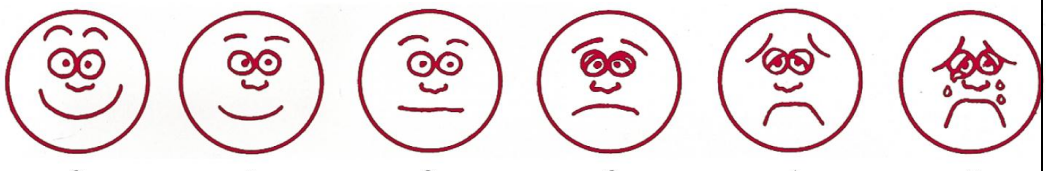
	Wong Baker face					
						
	0	1	2	3	4	5
Pulpectomy	2	0	1	0	0	0
Pulpotomy	3	1	3	0	0	0
Pragmatic	4	0	1	0	1	0

Table 7 Number of children in each group choosing each Wong Baker Face after completion of treatment

All subjects who completed the pulp treatment were asked to rate the treatment on the Wong-Baker faces scale. Table 7 shows that the majority of children rated their treatment as positive with 9 children from the 16 completing treatment choosing face 0 and 1 child choosing face 1. Only 1 child in the pragmatic treatment group gave a negative score of face 4, with the others, including 3 from the pulpotomy group, choosing face 2.

5.5 Clinical outcomes

	6 months n(N)	12 months n(N)	18 months n(N)	24 months n(N)
Pulpectomy	2(3)	1(2)	.	1(1)
Pulpotomy	5(7)	1(5)	0 (4)	1(3)
Pragmatic	5(5)	4 (5)	1(2)	0(2)

Table 8: Number of clinically successful teeth in each treatment group over time

Table 8 shows that at 6 months follow-up all teeth reviewed in the pragmatic treatment group showed absence of any clinical signs of infection, a clinical success rate of 100%. In the pulpotomy group, 5 of the 7 teeth reviewed were clinically successful (71%) and in the pulpectomy group 2 of the 3 teeth reviewed were clinically successful (66%).

At 12 months, one tooth in the pulpectomy group did not attend the review appointment and one tooth became mobile and was subsequently extracted so the clinical success rate reduced to 50%. The remaining tooth remained clinically successful until the end of the study.

In the pulpotomy group, the success rate dropped to 20% at 12 months and 33% at 24 months as the same tooth remained successful at 24 months but did not attend

an 18 month review appointment so the success rate was 0% at 18 months. Two teeth had exfoliated at 12 months and could therefore be said to be clinically successful.

In the pragmatic treatment group, the clinical success rate dropped over the follow-up time, from 4 teeth out of 5 (80%) at 12 months, to 1 out of 2 (50%) at 18 months and no teeth at 24 months. Again one tooth exfoliated at 18 months which could be deemed to be clinically successful.

	6 months			12 months			18 months			24 months			Total
	A	B	P	A	B	P	A	B	P	A	B	P	
Pain					1							1	2
Swelling		1			1	1		1					4
Sinus						1			1				2
Exudate	1												1
Mobility		1		1	3	1		4			4	1	14

Table 9 Number of teeth in each group showing clinical signs of failure over time (A= Pulpectomy group, B = Pulpotomy group, P = Pragmatic treatment group)

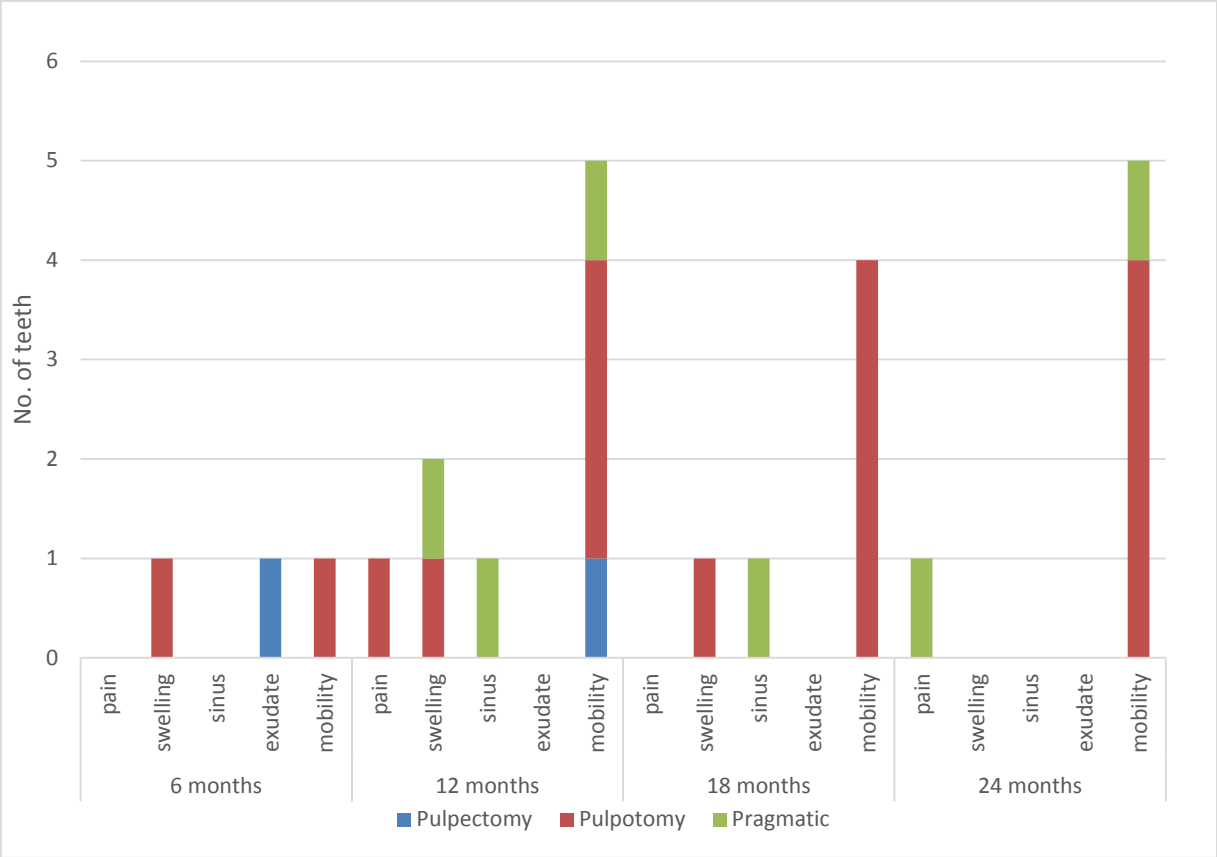


Figure 9: Clinical failures of teeth in each group over time

The majority of clinical failures were due to mobility particularly in the pulpotomy group where 1 tooth showed mobility at 6 months and this increased to 3 teeth at 12 months and 4 teeth at 18 and 24 months post treatment (Table 9 and Figure 9). The only 2 clinical failures in the pulpectomy group were due to exudate from the gingival margin at 6 months and mobility at 12 months. Some teeth showed more than one sign of failure.

5.6 Radiographic outcomes

The intra-examiner Cohen's kappa correlation coefficients for each finding on the 6 months radiographs are seen in Table 10.

Radiographic finding	Kappa score
Bifurcation radiolucency	0.5733
Periradicular radiolucency	0.7746
Pathological root resorption	0.4483
Length of root filling	0.5752

Table 10: Intra-examiner Cohen's kappa correlation coefficient for 6 month radiographs according to each radiographic finding

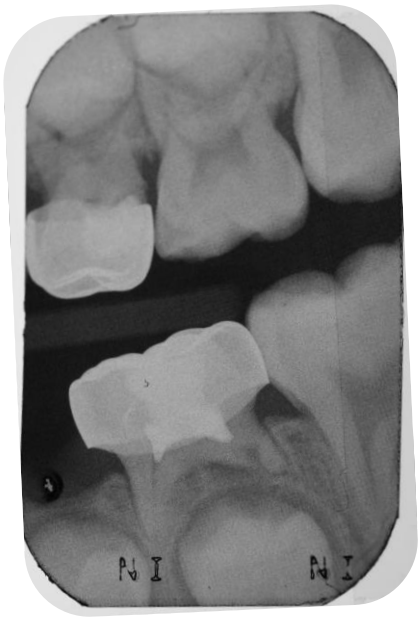


Figure 10: Vertical bitewing of pulpotomised lower left second primary molar at 6 months follow-up

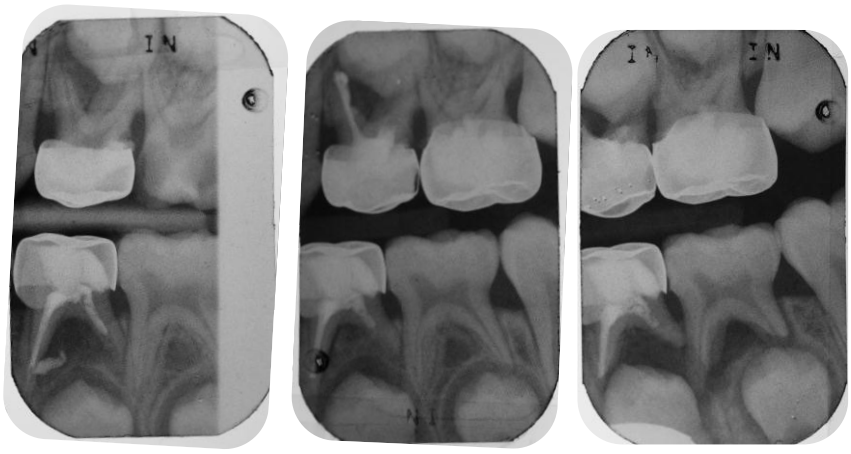


Figure 11: Vertical bitewings radiographs of pulpectomised lower left first primary molar immediately postoperatively, at 6 months follow-up and 12 months follow-up

	6 months n(N)	12 months n(N)	18 months n(N)	24 months n(N)
Pulpectomy	1(3)	2(2)	.	1(1)
Pulpotomy	5(7)	2(2)*	1(3)*	2(2)*
Pragmatic	2(4)*	3(4)*	1(1)*	2(2)

Table 11: Number of radiographically successful teeth in each treatment group over time where n = number of radiographically successful teeth and N = number of teeth reviewed * teeth reviewed but no radiograph taken

Radiographs were not taken for all teeth at each follow-up appointment. In the pulpectomy group one patient did not attend for clinical or radiographic follow-up at 18 months but returned at 24 months. In the pulpotomy group 1 tooth was not radiographed at 12 months because it was close to exfoliation, one tooth was not radiographed at 18 months as there was no clinical indication for radiographs and one 12 month radiograph did not show the roots of the tooth so could not be used for the study. In the pragmatic treatment group 1 patient did not attend for 6 month follow-up but returned at 12 months and 1 patient at 12 months and 1 at 18 months had no clinical indication for radiographs.

Table 11 shows that the majority of radiographic failures occurred in the first 6 months for all groups and at 18 months for the pulpotomy group when 2 teeth failed radiographically. Closer examination of these results shows that the majority of the failed teeth had bifurcation radiolucencies, accounting for 7 of the 10 radiographic failures (Table 12 and Figure 12). All of the bifurcation and periradicular radiolucencies present at 6 months were also present on the immediate post-operative radiographs so may represent healing lesions rather than new lesions. The

outcome measure was no resolution of bifurcation radiolucency at 12 months follow-up. Pathological root resorption was a new finding in both radiographs showing it.

	6 months			12 months			18 months			24 months			Total
	A	B	P	A	B	P	A	B	P	A	B	P	
Bifurcation radiolucency	2	2	1					2					7
Periradicular radiolucency			1										1
Pathological root resorption			1			1							2

Table 12: The number of teeth in each group showing radiographic signs of failure over time (A = Pulpectomy group, B = Pulpotomy group, P = Pragmatic treatment group)

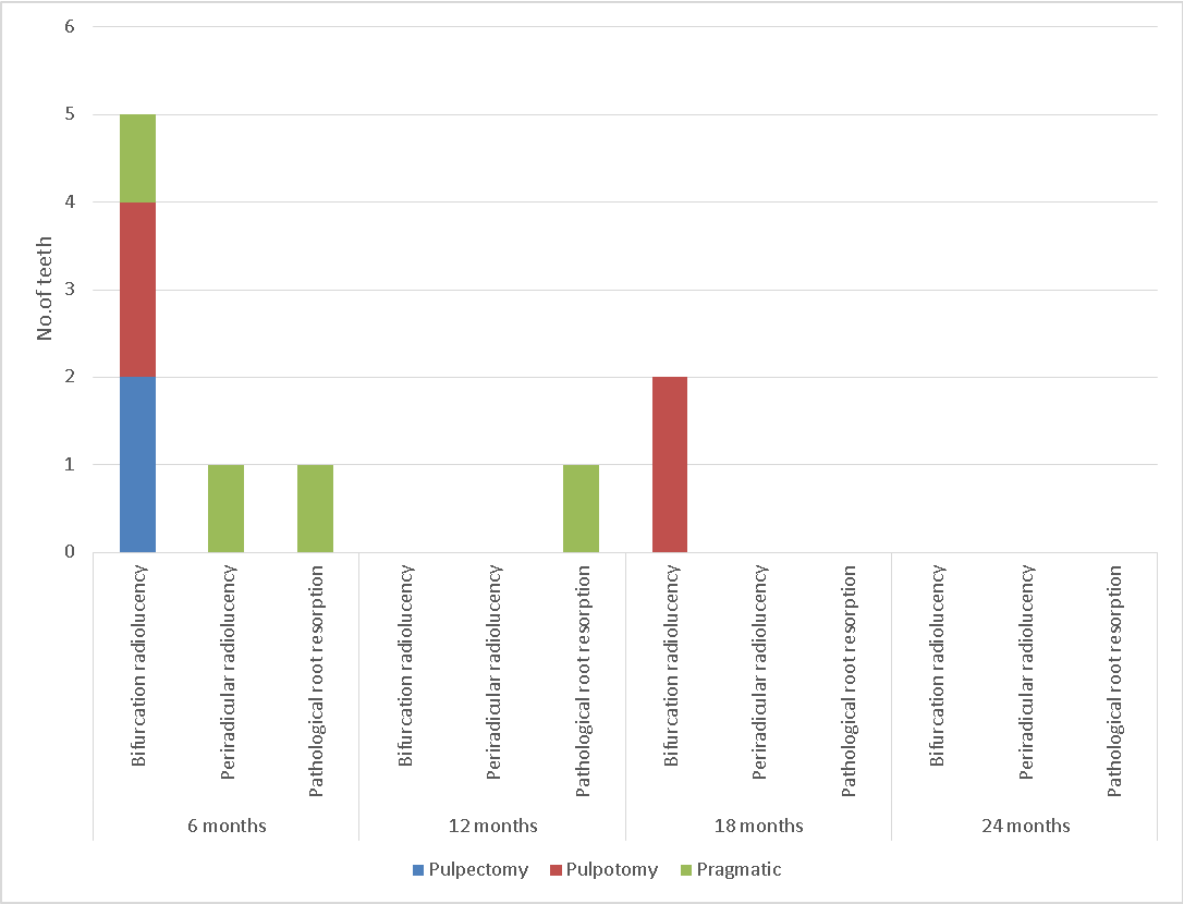


Figure 12: Radiographic failures of teeth in each group over time

5.7 Survival of teeth

A tooth was defined as successful in the absence of any of the clinical and radiographic signs of infection in Table 3 or if it exfoliated naturally. It was determined a failure if it had any signs of infection or was extracted at follow-up. At 6 and 12 months follow-up the pragmatic treatment group was most successful overall with 2 teeth (50%) clinically and radiographically successful at 6 months and 3 teeth (75%) at 12 months (Table 13). This is in comparison with 33% in the pulpectomy group and 42.8% in the pulpotomy group at 6 months and 50% of pulpectomised teeth and 75% pulpotomised teeth at 12 months (Table 13). These results are reversed at 24 months when the pulpectomy group is most successful but the numbers become smaller and in the pulpectomy group the same tooth survived the duration of the study.

	6 months n(N)	**12 months n(N)**	**18 months n(N)**	**24 months n(N)**
Pulpectomy	1(3)	1(2)	0(1)*	1(1)
Pulpotomy	3(7)	3(4)*	1(4)*	2(3)
Pragmatic	2(4)*	3(4)*	1(3)*	0(2)

Table 13: The number of teeth clinically and radiographically successful in each group over time where n = number of clinically successful teeth and N = number of teeth reviewed * teeth reviewed but no radiograph taken

Mobility was the most common reason for clinical failure especially in later follow-up. When the clinical sign of mobility is removed from the composite endpoint the results are seen in Table 14, showing improved success rates at 24 months when teeth would be mobile due to natural exfoliation.

	6 months n(N)	12 months n(N)	18 months n(N)	24 months n(N)
Pulpectomy	1(3)	2(2)	1(1)*	1(1)
Pulpotomy	4(7)	3(4)*	1(4)*	3(3)
Pragmatic	2(4)*	3(4)*	1(3)*	1(2)

Table 14: The number of teeth clinically and radiographically successful removing the outcome of clinical mobility from the composite endpoint where n = number of successful teeth and N = number of teeth reviewed * data missing as tooth reviewed and radiograph not taken or tooth not reviewed at this stage

Bifurcation radiolucency was the most common reason for radiographic failure especially at 6 months follow-up. If the presence of bifurcation radiolucency is removed from the composite endpoint, the results are seen in Table 15, showing improved success rates in the pulpectomy and pulpotomy groups at 6 months and the pragmatic group at 12 months.

	6 months n(N)	12 months n(N)	18 months n(N)	24 months n(N)
Pulpectomy	2(3)	1(2)	0(1)*	1(1)
Pulpotomy	5(7)	3(4)*	1(4)*	2(3)
Pragmatic	2(4)*	3(4)*	1(3)*	0(2)

Table 15: The number of teeth clinically and radiographically successful when the presence of a bifurcation radiolucency is removed from the composite endpoint where n = number of successful teeth and N = number of teeth reviewed * data missing as tooth reviewed and radiograph not taken or tooth not reviewed at this stage

5.8 Examples of clinical cases

5.8.1 Case B001

Case B001 was a 5 year old boy who had a pulpotomy carried out on the lower righ second primary molar (tooth 85). He rated his treatment as 0 on the Wong-Baker faces scale. At baseline he had pain, swelling and a sinus and a bifurcation radiolucency was noted radiographically (Figure 13a). The tooth was dressed with Ledermix® for one week and a pulpotomy carried out according to the protocol.

Immediately post-operatively the clinical and radiographic signs had resolved (Figure 13b). At 6 months and 12 months follow-up the tooth remained asymptomatic clinically and radiographically. Unfortunately he was not seen at 18 months but at 24 month follow-up there were still no clinical or radiographic signs of infection. The pulp treatment was therefore deemed successful despite a short root filling especially in the mesial root.

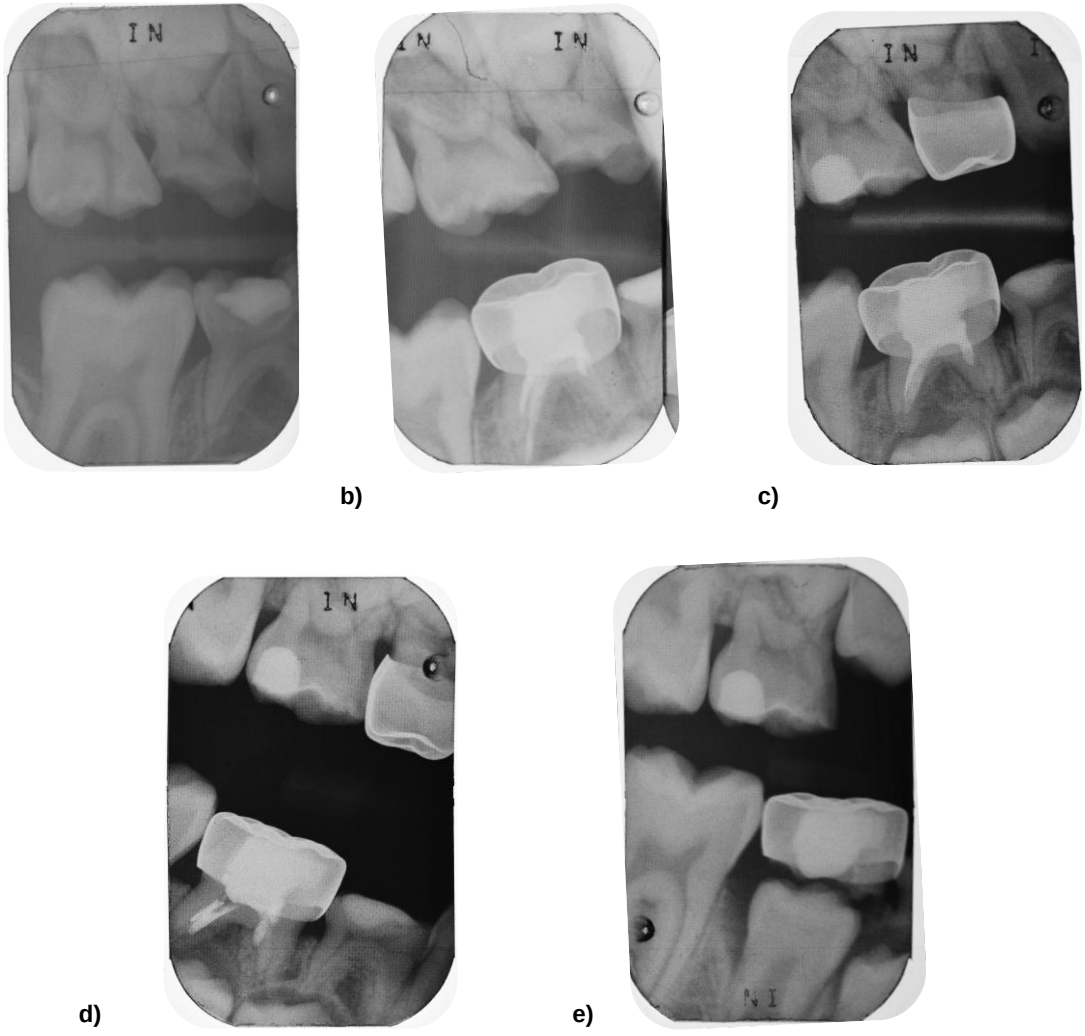


Figure 13: Radiographs for case B001. a) Baseline, b) postoperative, c) 6 months, d) 12 months and e) 24 months follow-up

5.8.2 Case L007

Case L007 was a 6 year old boy who had a pulpectomy on the lower left first primary molar and pulpotomies on both upper first primary molars. He scored all treatments as 0 on the Wong-Baker faces scale.

The lower primary molar (tooth 74) had pain, swelling and a sinus at baseline and no radiographic signs of infection. It was dressed with Ledermix® for one week before completing the pulpectomy. Immediately postoperatively there was exudate at the gingival margin and a bifurcation radiolucency. At 6 months follow-up all clinical signs had resolved but the bifurcation radiolucency remained. At 12 months the tooth became mobile and the bifurcation radiolucency appeared to have resolved but this was difficult to assess as the follicle of the premolar was close to the bifurcation and there was evidence of infection on the second primary molar (Figure 14d). The tooth was extracted by 18 months.

The upper right primary molar (tooth 54) had pain, swelling, sinus, exudate and mobility at baseline but no radiographic signs of infection. It was not dressed with Ledermix® and immediately after the pulpotomy treatment still had all the clinical signs of infection but no radiographic signs. At 6 months the pain, sinus and exudate had resolved but a swelling was still present and there were still no radiographic signs. The tooth had exfoliated by 12 months.

The upper left primary molar (tooth 64) was previously treated with an indirect pulp cap and preformed metal crown but presented with a sinus at a review appointment. There were no radiographic signs of infection. It was subsequently treated with a pulpotomy through the preformed metal crown. Immediately after the

pulpotomy the sinus was still present and there a bifurcation and periapical radiolucency were also present. At 6 months all had resolved clinically and radiographically and the tooth had exfoliated by 12 months.

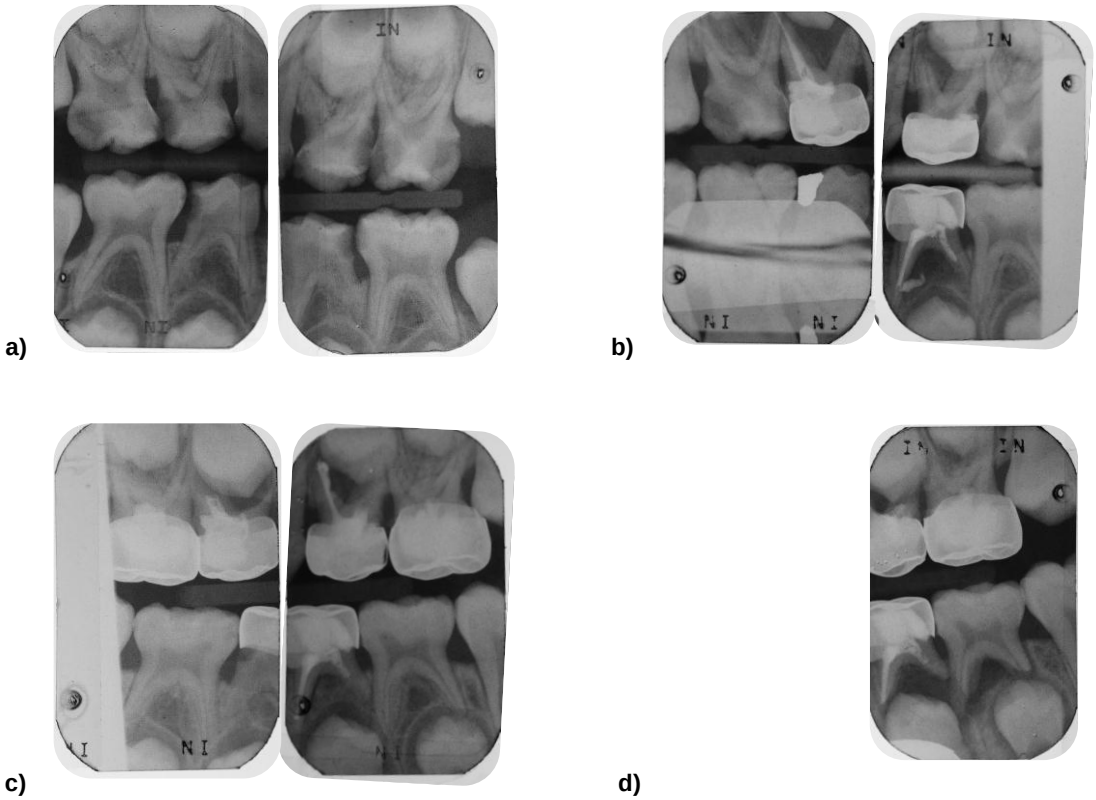


Figure 14: Radiographs for subject L007. a) Baseline vertical bitewings, b) Immediate post-operative radiographs 54 and 74 and preoperative 64, c) 6 month follow up 54 and 74, immediate post-operative 64, d) 12 months radiograph 74 and 6 months 64

5.9 Summary

Recruitment of subjects was difficult with only 15 children, 22 teeth recruited to the study. Most children screened were not recruited because they did not have non-vital primary teeth or they had insufficient cooperation for the pulp treatments or radiographs. The retention of subjects within the study was good with only 3 children failing to attend follow-up appointments and the majority of those children who took part found all treatments acceptable.

The most common reason for clinical failure was mobility and the pragmatic treatment group were most successful clinically in the early stages (6 and 12 months) of follow-up. The most common radiographic reason for failure was the presence of a bifurcation radiolucency, with the pulpotomy group most successful radiographically at 6 and 12 months and all groups having 100% radiographic success at 24 months. Overall success rates were better in the pragmatic and pulpotomy group early on and in the pulpectomy group at 24 months.

CHAPTER 6: DISCUSSION

6.1 Summary of findings

Recruitment of patients to the study was difficult. Over a one year period only 109 children were assessed as suitable from the referrals which were placed on the anxious child waiting list at the Lyng Health Centre. The majority of referrals on this waiting list were slightly older children who required restoration of first permanent molars under inhalation sedation. This may reflect the referral patterns of general dental practitioners in this region who may not refer anxious children for restoration of primary teeth or may refer directly for extractions under GA if the teeth become non-vital. There was also a high percentage (43.1%) of children who cancelled or did not attend their assessment appointment. This may be due to the long waiting times from referral to assessment and the low importance parents place on restoration of primary teeth in the absence of symptoms.

Only 11 children at the Lyng Health Centre and 4 children at Birmingham Dental Hospital were suitable for recruitment to the study over the year. 15 children (29.4%) had no non-vital primary teeth which was difficult to assess from the referral letters received and again may reflect the referral patterns of general dental practitioners with symptomatic teeth being referred for extraction under GA which often has a shorter waiting list. The other reasons for children being unsuitable for the study were lack of cooperation for treatment (25.5%) and/or preoperative radiographs (9.8%). The children were taken from referrals for treatment due to anxiety so insufficient cooperation may be a feature of this cohort of patients. The more cooperative patients may have been effectively treated in general dental practice. In addition, the

children who were unsuitable for the study tended to be younger (age 4-6 years) whilst the majority of those recruited were 6 years old. Older patients are more likely to be cooperative with treatment. There was also a higher percentage of white British children in the study group which may reflect difficulties in communication with children and parents from other ethnicities and differences in culture which may affect behaviour in the dental surgery and attitudes towards restoration and retention of primary teeth.

Once the children were recruited to the study, 6 children (28.6%) were not cooperative enough for local anaesthetic and/or rubber dam placement so could not be randomly allocated into the pulpectomy or pulpotomy group and were therefore placed into the pragmatic treatment group. This was better than the original estimate of 40% of children without sufficient cooperation for randomisation. However, once they were randomly allocated to each group 3 children could not tolerate and complete the treatment in the group they were allocated to, 2 from the pulpectomy group and 1 from the pulpotomy group. This may imply these treatments were less acceptable to patients than the pragmatic treatment and give a different view from the results obtained when asking the child how they felt about the treatment immediately post-operatively using the Wong-Baker FACES scale. Using this scale for those who completed treatment, 56.3% rated their treatment positively, 31.3% as average and only one child in the pragmatic treatment group gave a negative response. In addition, all teeth in which the pulp treatment failed were extracted with local anaesthetic and/or inhalation sedation and no child required GA for extractions. This suggests that the pulp treatments did not make children more anxious regarding dental treatment and may have helped with acclimatisation to treatment. The relief of

symptoms for at least a year in the pragmatic treatment group may also have allowed time for the child to be acclimatised to dental treatment, have other restorative treatment carried out and also mature emotionally so they are more able to cope with an extraction.

Of the children who received the pragmatic treatment, 4 out of 6 (67%) cooperated for local anaesthetic but none cooperated for rubber dam placement which suggests that rubber dam isolation is more difficult for children to tolerate than the local anaesthetic. The one negative score on the Wong-Baker FACES scale was in this group and was from a child who had local anaesthetic for an upper first primary molar but no rubber dam. He subsequently had treatment on a lower first primary molar with no local anaesthetic, having admitted anxiety about needles and rated the second treatment 0 on the Wong Baker FACES scale. His rating for the first tooth may therefore have been related to the local anaesthetic rather than the treatment itself.

After completion of treatment, only 3 subjects with 3 teeth (18.8%) did not attend for follow-up, 1 at 6 months, 1 at 12 months and 1 at 18 months with the first 2 of these being in the pulpectomy group. This may imply successful treatment because if the teeth were asymptomatic the parents may feel follow-up is not required or it could indicate failure because the tooth has been extracted elsewhere. It may also suggest issues with the acceptability of these complex restorative techniques with the children reluctant to re-attend the dental surgery even for examination.

Fewer teeth in the pulpotomy group (3 out of 8) required an interim dressing with Ledermix® despite a higher number complaining of pain or having evidence of

gingival swelling and/or sinuses (5 out of 8). This might suggest that clinical signs are not an indication of the degree of infection and inflammation present within the pulp chamber and root canals.

With such small numbers completing the treatment it is difficult to draw reliable conclusions regarding the clinical and radiographic outcomes of each technique. However, the results do suggest the pulpotomy group was as successful if not more so than the pulpectomy group at all follow-up intervals and the pragmatic treatment group appears to perform at least as well as the pulpectomy group at 6 and 12 months follow-up. It would also appear that if a pulp treated tooth is clinically successful at 12 months it will either exfoliate or survive until 24 months. This occurred with the remaining clinically successful teeth in the pulpectomy and pulpotomy groups but not the pragmatic treatment group.

The most common reason for clinical failure was mobility particularly at the later follow-up appointments (18 and 24 months) and in the pulpotomy group with 4 out of 4 teeth reviewed being mobile. As the majority of these teeth were otherwise clinically successful, this mobility may have been physiological rather than pathological and therefore the success rates indicated in Table 14 may be more accurate. One tooth in the pulpotomy group actually exfoliated at the 24 month follow-up appointment. The physiological mobility of teeth and exfoliation of 5 teeth during the study period appears to show premature exfoliation of pulp treated primary molars especially in the pulpotomy group, with one child having lost 2 primary molars at 12 months follow-up aged only 7 years old. Radiographically these teeth showed no signs of pathological root resorption but there was accelerated physiological root

resorption in the absence of accelerated eruptive movement of the permanent successor (Figure 10). This may be due to resorptive processes starting at the apices when the pulp becomes inflamed and, although the inflammatory process is arrested by pulp treatments and the medicaments placed, the root resorption continues at the accelerated rate.

Of the successful teeth at 6 months follow-up only 3 teeth failed radiographically at further follow-up appointments (1 in the pragmatic treatment group and 2 in the pulpectomy group). Bifurcation radiolucencies were the most common reason for radiographic failure, accounting for 70% of failures at 6 months follow-up. However, 100% of those showing a bifurcation radiolucency at 6 months had a bifurcation radiolucency immediately pre-operatively. This would imply that the pre-operative status of the tooth had more effect on the radiographic status at 6 months than the treatment provided. These radiolucencies could also be viewed as healing lesions rather than failures and should be monitored for a further 6 months in the absence of clinical signs of failure (Figure 11) as the outcome measure used in this study was failure of resolution of a bifurcation lesion at 12 months (Table 3). The results shown in Table 15 are therefore a more accurate representation of the success rates of the different techniques.

The Kappa scores for the radiographs are low for the presence of a bifurcation radiolucency (0.5733), pathological root resorption (0.4483) and the length of the root filling (0.5752) but good for the presence of a periradicular radiolucency (0.7746). This highlights the difficulties encountered when taking and analysing radiographs of young children due to positioning problems and the presence of the permanent

successor and its follicle which often overlap the furcation region of the primary molar and cause physiological root resorption which is difficult to differentiate from pathological root resorption. The low result for the root filling may be due to different lengths of root filling in multiple roots as can be seen in Figure 12. In addition, there were very few positive radiographic findings so the expected agreement for the Kappa calculation for each category is high.

6.2 Critique of the method

The numbers recruited in this study were much less than planned and this makes it difficult to draw any meaningful conclusions about differences between the treatment arms. However, this was a pilot study and one of the aims of the study was to assess the feasibility of patient recruitment, cooperation with treatment and return for follow-up appointments. Patient recruitment was the most difficult aspect of this study and highlights issues with conducting randomised controlled trials on young children. One of the main reasons that pulpectomies are not routinely provided for paediatric patients is the lack of cooperation of many children with significant carious lesions. Many of the children assessed for this study needed significant acclimatisation to dental treatment and management of multiple carious lesions but they also had pain or infection which required immediate management. The options were therefore to either attempt the pulp treatment first when cooperation was not optimal or wait until the child was sufficiently acclimatised to dental treatment and other treatment had been carried out when their motivation for treatment was starting to wane and the tooth had either been painful or temporarily dressed for several months. Trying to standardise preoperative assessment, pulp treatments and follow-up to get valid results from a randomised controlled trial may not be the most

appropriate method for this cohort of patients. A more pragmatic study design which treats the tooth depending on the cooperation and other dental treatment needs of the child may be more appropriate.

Block randomisation worked well in this study as equal numbers entered each arm, despite the study being carried out across 2 sites. The researcher (JM) carrying out the treatment knew the size of the blocks so could have introduced some selection bias by delaying less cooperative children's treatment until the more straightforward pulpotomy arm was to be allocated. The risk of this occurring was minimised by randomly assigning group A or B in blocks of 4 to 60 numbered opaque envelopes. Half of these were taken to each site and a random envelope opened once the tooth had been anaesthetised and isolated with rubber dam. This ensured the allocation was concealed until the last moment. In addition, if cooperation was not deemed sufficient for pulpectomy treatment the child was placed straight into the pragmatic treatment group.

Blinding of the operator was not possible due to the difference in the 3 techniques but the subjects were theoretically blind to which arm of the randomised part of the trial they were in as both arms required rubber dam placement and a stainless steel crown afterwards. The operator also carried out the majority of the clinical follow-up assessments so may have remembered which group the tooth was in, leading to some observation bias. This information was also available within the patient's clinical notes. This could have been avoided by having a different assessor for clinical follow-up as all study teeth looked the same post-operatively having been restored with preformed metal crowns.

The radiograph assessor was blind to which treatment group each tooth was in. However pulpectomy treatments, which involve instrumenting the root canal and placing paste within the root canal, will be more likely to have longer root fillings with Vitapex® than pulpotomy treatments, where the paste is placed over the root canal orifices only. This was not always the case though as the second radiograph in Figure 12 shows, the upper left first primary molar was treated by pulpotomy and the lower left first primary molar by pulpectomy. The risk of observation bias from the radiograph assessor was therefore minimised as much as possible.

The Kappa scores highlight difficulties in interpreting radiographs of primary teeth due to the overlap of the permanent successor especially in the furcation region and physiological root resorption. The interpretation of the radiographs may have been impaired further by the use of wet films which were photographed and viewed on a PC monitor. This may have introduced additional inaccuracies due to processing differences, lighting and photographic exposure differences. Positioning of the film is also more variable in paediatric patients and the roots of one tooth in the pulpotomy group were missed on the radiograph taken at 12 months but there was no clinical indication to repeat the radiograph and expose the child to further radiation. The obligation to reduce radiation exposure in paediatric patients also led to radiographs not been taken for some children at follow-up because there was no clinical indication and/or the tooth was close to exfoliation which meant a reduction in the number of subjects at some follow-up appointments and limits the validity of the results.

The children were asked to rate how they felt about the treatment they had received immediately after the treatment which reduced recall bias. However, they were asked by the dental nurse who had assisted during the treatment which would have introduced response bias as the children may have responded more positively in order to please the dental team who they would see again for follow-up appointments. This may have over exaggerated the children's satisfaction with the treatment received. This could be improved by asking the children to rate the treatment anonymously by electronic means for example on a tablet or by logging on to a website.

Teeth were not always followed up at exactly 6, 12, 18 and 24 months after the pulp treatment was completed which may have over or underestimated the success rates for each group. There were several reasons for this. Some children had other dental treatment that needed to be completed so the teeth involved with the research project were reviewed when they were attending the dental clinic for the other treatment to minimise the number of appointments and avoid inconvenience for the family. Some children had multiple teeth involved in the study and pulp treatments were undertaken at different times on different teeth so in order to minimise the number of radiographic exposures, vertical bitewing radiographs showing 2 pulp treated teeth were taken as close to the standard follow-up times as possible for both teeth. In addition, the assessors did not rregularly work at the Lyng Health Centre once the recruitment phase was completed so follow-up sessions were only booked in as required and when a dental surgery and the assessor and research dental nurse were available. Therefore, if a child was unable to attend the appropriate follow-up session they may not have been able to be seen again for several months.

This meant that some results, especially between 12 and 18 months, were rounded up or down to the nearest appropriate follow-up point. It also led to shorter periods between some follow-ups and repeating the radiographs at less than 6 month intervals could not be justified for the purposes of the research. This led to missing clinical and radiographic data at 18 month follow-up for one patient in the pulpectomy group. This could be improved by calibrating more clinicians to assess the teeth involved in the study clinically and radiographically at standardised recall appointments. Multiple assessors would however introduce more variation into the results and they would need to be carefully calibrated and inter-rater assessments undertaken at regular points throughout the study. Alternatively, one assessor based permanently at the dental clinic where the research is carried out who is different from the researcher undertaking the pulp treatments would also mean the clinical assessments are blind as well as ensuring review occurs as close as possible to the set follow-up times.

6.3 How the results fit in with published data

From 109 eligible referrals to the Lyng Health Centre only 62 children attended for assessment (56.9%) and only 11 of these children were suitable for the study (17.7%). The FiCTION trial is recruiting a similar population of children (age 3-7 years old with at least one primary molar with caries extending into dentine) for randomisation into one of three different groups. They had anticipated problems with recruitment of subjects for the study based on previous studies of recruitment to randomised controlled trials and particularly issues with recruitment of children. In addition they were recruiting from 50 different primary general dental practices (Keightley et al., 2014). They undertook a pilot study of 11 practices (20 dentists) with

a target of 200 children to recruit but only 50% of the expected number of participants were recruited by the end of the trial (Keightley et al., 2014). Patients, parents and dentists were questioned following the pilot study about involvement in the trial and recruitment and how it could be improved. Dental teams felt that the involvement of the whole dental team was important in terms of administration and patient queries but that a face to face discussion about the project with a dentist that was respected and trusted was more important than study information for parents to enroll their child in the trial. Dentists also felt that parents preferred appointments outside of school time and this was important when recruiting children and providing the treatments (Marshman et al., 2012).

Despite putting measures in place to address these issues, the FiCTION trial team anticipated a 65% attendance rate for screening visits with 15% of these children being eligible for the study and 80% of these consenting to take part from the results of the pilot study (Innes et al., 2013). The children in the FiCTION trial require bitewing radiographic examination in line with FGDP guidelines and this was one area that the dental practitioners were concerned about and stated that they often did not take radiographs in general practice for children under 6 years old (Marshman et al., 2012). An inability to tolerate radiographs showing the periapical area was one of the most frequent reasons for ineligibility in this study and would also preclude the pulpectomy technique being undertaken in primary dental practice for the majority of children with non-vital primary molars. The extent of caries in subjects is also less in the FiCTION trial, they are recruiting dentinal caries only and are excluding those who present with pain and infection which was anticipated to be only 3% of those screened. This study recruited those with signs or symptoms of

infection which the Chid Dental Health Study 2013 found were present in 4% of 5 year old children (Health and Social Care Information Centre, 2015). The recruitment rates in this study therefore appear good when looking at the population we were aiming to recruit and comparing with the anticipated recruitment rates for the FiCTION trial. This would imply that recruitment needs to be undertaken from a wider population, either directly from general dental practitioners, those referred for extractions under general anaesthetic or from multiple centres. Recruitment could also be improved by ensuring involvement of the whole dental team. At the Lyng Health Centre the receptionists and other clinical staff were aware of the project being undertaken but the principal investigator and research dental nurse were only there one day per week and they were responsible for booking all of the patients' appointments and answering any patient or parent queries. This also limited the recruitment and treatment sessions to one day per week and therefore meant time taken out of school which was highlighted as a potential problem with recruitment following the FiCTION pilot trial (Marshman et al., 2012).

A systematic review of characteristics that predict recruitment to randomised controlled trials found that ethnic minorities, parents with lower educational attainments and those with a lower socio-economic status may be less likely to enrol in non-medical randomised controlled trials. Fewer studies in the review reported on the child characteristics that affected recruitment but there was a trend towards younger children (age 5-9) being more likely to drop out of trials (Robinson et al., 2016). Unfortunately children in ethnic minorities, lower socio-economic status areas and with low educational attainment of parents are the most likely to have significant dental caries and non-vital primary teeth and so they are the population this trial was

targeting (Health and Social Care Information Centre, 2015, Davies et al., 2012). This means that additional efforts would be required to recruit sufficient numbers of children for a full scale randomised controlled trial even before considering the inclusion criteria of having a non-vital primary molar and sufficient cooperation for radiographs and a pulpectomy treatment. A randomised controlled trial may therefore not be the most appropriate study design for this particular population of patients and an observational study may give more valid results.

The success rates in the pulpectomy group in this study were less than in other studies. Mortazavi and Mesbahi (2004) found all teeth had absence of clinical signs and symptoms of pain, fistula and intra and extra-oral swelling and 78.4% of teeth obturated with Vitapex® had no abnormal mobility at 3 months. 77.8% also demonstrated regeneration and reduction in size of a radiolucency if present preoperatively. At 10-16 months 100% of teeth treated with Vitapex® showed no abnormal mobility and resolution of bone radiolucency. This compares with 66% success at 6 months and 100% at 12 months in this study when mobility and bifurcation radiolucency are removed from the composite endpoint. The increased success rates in the study by Mortazavi and Mesbahi may be due to the use of formocresol in a 2 visit pulpectomy technique. Otherwise the method of calculating working length from the preoperative radiographs was the same as this study but irrigation was with sterile saline and the teeth were restored with amalgam not preformed metal crowns.

Trairatvorakul and Chunlasikaiwan (2008) used a one-visit pulpectomy technique and found 78% of primary teeth treated with Vitapex® were clinically and

radiographically successful at 6 months and 89% at 12 months. They looked at the absence of abnormal mobility and a reduction in size of any pathologic inter-radicular and/or periapical radiolucencies so if this is compared with the overall success rate removing mobility and bifurcation radiolucencies, the success rate in this study is better at 12 months at 100% but worse at 6 months (66%) due to one tooth having exudate at the gingival margin. This is a limitation of the small numbers in this study but the reduced success could be due to estimation of the working length from preoperative radiographs compared with determination by an electronic apex locator in Trairatovorakul and Chunlasikalwan's study. In addition, Trairatovorakul and Chunlasikalwan used 2.5% sodium hypochlorite which is a more potent antimicrobial agent than chlorhexidine. They also checked whether the root canals were completely filled radiographically before coronal restoration and if not they were refilled suggesting that all teeth in their study were ideally obturated to working length with Vitapex®.

Ozalp et al. (2005) also used a one visit technique, took a working length radiograph with files in the canal, irrigated with 5% sodium hypochlorite and 0.5% metronidazole solution and restored with amalgam. They found 100% clinical and radiographic success for teeth obturated with Vitapex® when followed up every 2 months for 18 months. However, they also had to re-treat 6 out of 20 teeth because of resorption of Vitapex® in the root canal, one tooth at 6 months, 2 at 8 months and 3 at 12 months. This replacement of the root filling may account for improved success but it may also be due to the choice of irrigant.

Nurko and Garcia-Godoy (1999) reported a 100% clinical and radiographic success rate over 3-22 months. It is difficult to compare the results of this study directly with the current study as it is a retrospective review of the treatment and relies on records being present for follow-up at least 3 months post-operatively. The failures may not have this follow-up. In fact, closer inspection of the results finds at least 1 patient had clinical signs of pain and infection 1 day after the treatment and had a tooth extracted reducing the clinical success rate to 97% and one patient had a bifurcation radiolucency post-operatively reducing the radiographic success to 97%. The paper does not state how working length was determined but they used water for irrigation and restored the teeth with a preformed metal crown in a one visit technique.

Pramila et al. (2015) used a very similar technique to this study, with working length determined by preoperative radiograph, chlorhexidine 2% used as a final irrigant, one visit pulpectomy technique if there was no extra-oral swelling and placement of a preformed metal crown at the same visit. Their clinical success rates for Vitapex® were better than this study with 100% successful over 30 months but radiographic success was 80% at 6 months, 82% at 12 months and 90% at 30 months in comparison with this study's results of 66% at 6 months, 100% at 12 months and 100% at 24 months. Louwakul and Prucksathamrongkul (2012) also used same technique and their overall success rates with chlorhexidine irrigation were 100% at 6 months, 97% at 12 months and 93% at 18 months. However, both studies included only mandibular molar teeth to enable easier identification of furcation radiolucencies which may account for the reduced radiographic success rate compared with the present study despite otherwise similar conditions.

The success rates in this study could therefore have been improved by using sodium hypochlorite as an irrigant instead of chlorhexidine. However, sodium hypochlorite could not be used in the pragmatic treatment group due to its soft tissue irritant effects and unacceptable taste when rubber dam isolation is not possible. The use of a more accurate determination of working length, either with a working length radiograph or electronic apex locator, would increase the chance that the root canals were cleaned and obturated to within 2mm of the apex which Ozalp et al. (2005) found had the best chance of clinical and radiographic success without resorption of the material within the root canals.

The premature exfoliation of primary molars in this study as well as accelerated physiological root resorption agrees with work by Trairatvorakul and Chunlasikaiwan (2008) and Moskovitz et al. (2012) who demonstrated significantly higher root resorption in endodontically treated primary molars filled with a paste containing iodoform, zinc oxide and calcium hydroxide compared with their homologous teeth. However Ballesio et al. (2002) found no alteration in physiologic resorption after copious irrigation with 10 vol hydrogen peroxide and 3% sodium hypochlorite and dressing with powdered macrolide antibiotic and glycerine for 8-10 days, followed by filling with a mix of powdered antibiotic, glycerine and zinc oxide eugenol. This would suggest that the technique described in this study may not remove all infected material, leaving a low grade asymptomatic inflammation in the periapical tissues which accelerates root resorption.

6.4 Implications of research findings

This study suggests that a non-root canal instrumentation pulpotomy may have equivalent clinical and radiographic success to the gold standard pulpectomy. However, the small numbers of subjects limit the clinical application of the results. It has therefore provided useful information for further research into the clinical feasibility of the pulpotomy technique.

The problems with recruitment of patients could be lessened by a change in study design. A randomised control trial requires the subjects in each arm to be equivalent so participants must be capable of tolerating either pulp treatment technique if they are to be effectively randomised into either arm. However, the pulpotomy technique is more likely to be used for less cooperative children as it is less time-consuming and less technique sensitive than a pulpectomy. A prospective observational study may give more valid results for the study population. The children who have sufficient cooperation would receive pulpectomies and those who are not as cooperative or who cannot tolerate radiographs showing the periapical area would have pulpotomies with or without local anaesthetic or rubber dam isolation. Seemingly the majority may tolerate local anaesthetic but not rubber dam. Both groups would be followed up clinically, and radiographically where possible, at 6 month intervals until exfoliation. This would improve the recruitment of patients to the study and give results for the effectiveness of the pulpotomy in comparison to the gold standard pulpectomy treatment. If the success rates were found to be equivalent, then cooperative children would have the option of either treatment.

The need for preoperative radiographs showing the root apices must also be questioned as only 2 out 19 preoperative radiographs showed periapical

radiolucencies. Unless the child was having a pulpectomy where the working length of the root canals needed to be estimated from a preoperative radiograph, a diagnosis of loss of vitality could be made from clinical signs and/or horizontal bitewing radiographs which show the bifurcation region, and treatment could be completed as per the protocol. This may improve recruitment to the study as horizontal bitewing radiographs are easier to tolerate and 9.8% of those screened at the Lyng Health Centre could not be recruited as they could not tolerate radiographs.

The importance of an accurate determination of the working length of root canals for pulpectomies is demonstrated by improved success rates in other studies which used more accurate measures than estimation from the preoperative radiograph, as used in this study. Recent studies and a meta-analysis by Ahmad and Pani (2015) have shown improved accuracy of electronic apex locators in primary molars. Their use could be considered in future studies to limit the radiographic exposure of the subjects, improve the acceptability of the procedure for the child and operator, reduce the time taken to complete treatment and increase the success of the treatment by debriding and obturating the root canals to the optimum length.

If radiographs were to be used for a future study, digital radiographs could reduce the effective radiation dose for children and would provide a more standardised image for viewing on a monitor with sufficient resolution for viewing radiographs. This may minimise inaccuracies and improve analysis of the radiographic outcomes.

The FiCTION trial protocol indicates that the recruitment rates in this study were as would be expected for non-vital primary molars (Innes et al., 2013). Therefore, to increase the number of subjects they must be recruited from a wider area and from

alternative sources such as directly from general dental practice and undergraduate dental and hygiene and therapy student clinics at the dental hospital and outreach community clinics. This may also increase the number of cooperative patients recruited as they have not been referred due to anxiety or may already have had some acclimatisation to dental treatment by the general dental practitioner or students. Another potential source of subjects would be those children referred for extractions under GA as they often have more extensive caries and/or symptoms of pain or infection. At the time this study was set up children referred to Birmingham Dental Hospital had their pre-operative assessment for extractions under GA at the hospital on the same day as the GA. The children therefore attended the hospital fasted and expecting treatment to be carried out, so their parents may have been reluctant to participate in a research project which might delay their child's dental treatment, especially in the presence of symptoms. The system has now changed so that children attend the hospital for a pre-assessment visit at least a week before the GA. Parents may therefore be more inclined to take part in the research project if their child might avoid the need for a GA and extraction of multiple carious teeth. A pilot study would be required initially to assess the recruitment rates of children from these sources and if it was still unlikely that sufficient numbers would be recruited then a multicentre randomised control trial could be considered. A multicentre trial would increase the external validity of the study but would increase operator bias. Multiple operators and assessors would need to be trained and calibrated to ensure standardised methods, materials and data collection.

The finding that several teeth exfoliated earlier than expected and physiological root resorption appeared accelerated agreed with other studies using chlorhexidine

irrigation and ZOE or calcium hydroxide and iodoform root filling materials (Trairatvorakul and Chunlasikaiwan, 2008, Moskovitz et al., 2012). The reasons for the accelerated root resorption and the exact mechanisms are not currently known but one theory is that infection in the periapical tissues stimulates the formation of odontoclasts. If the infection is not completely removed by effective mechanical debridement, irrigation with a potent antimicrobial, obturation with an antimicrobial paste and effective seal of the root canal filling and coronal restoration, then a low grade asymptomatic inflammation may continue in the periapical tissues and root resorption may continue at an increased rate. Microscopic evaluation of the periapical region of exfoliated and extracted primary molar teeth which have undergone non-vital pulp treatments may further our understanding of this process. They could be compared with non-vital primary molars which have not undergone pulp treatments and those exfoliating naturally.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

7.1 To assess the long term survival of primary molars treated by either method and determine any difference in effect size

The overall success rate over 2 years in the pulpectomy group was 1 tooth out of 7 (14%) but 3 did not complete treatment and 2 did not return for follow up, giving a 50% success rate. Six teeth out of 8 were successful in the pulpotomy group with one failing to complete treatment, an 86% success rate. One tooth out of 6 was successful in the pragmatic treatment group, with one failing to complete treatment and one failing to return for follow-up, a 25% success rate. However, at one year follow-up the pulpectomy group had a 50% success rate (1 out of 2 teeth), the pulpotomy group had a 100% success rate (7 out of 7 teeth) and the pragmatic group had a 60% success rate (3 out of 5 teeth).

The numbers are too small to draw any meaningful conclusions but indicate that a 'Scottish/non-root canal instrumentation pulpotomy' with rubber dam isolation has potential as an alternative to a pulpectomy and may be more successful when using chlorhexidine as an irrigant. Without rubber dam isolation, which all children in the pragmatic treatment group found difficult to tolerate, success rates were reduced over 2 year follow-up but promising for 1 year follow-up. This may allow sufficient time for cooperation to improve enough to allow extraction with LA or pulpectomy treatment with rubber dam isolation. All of the failures in this study had extraction of the tooth with LA and/or inhalation sedation.

7.2 To investigate clinically and radiographically resolution of infection and symptoms

The majority of children presented with clinical symptoms of pain at baseline; 57.1% pulpectomy group, 75% pulpotomy group and 100% of the pragmatic group. This was completely resolved at 6 months with no children complaining of pain. One tooth out of 9 with a swelling at baseline still had a swelling present at 6 months, this tooth was in the pulpotomy group and exfoliated shortly after the review appointment. All sinuses resolved after 6 months and one tooth with exudate from the gingival margin at baseline resolved after treatment. All teeth which were mobile at baseline were no longer mobile at 6 months follow-up.

Radiographically all teeth with bifurcation radiolucencies at baseline eventually resolved, 2 teeth after 6 months (both in the pulpotomy group), 2 teeth after 12 months (1 pulpectomy group and 1 pragmatic group),1 after 18 months (pulpotomy group) and 1 after 24 months (pragmatic group). Only two teeth had periapical radiolucencies at baseline, one failed to return for follow-up and one in the pragmatic group still had a periapical radiolucency as well as a swelling and sinus at 12 months so was extracted.

7.3 To record any complications occurring from either technique

The major complication from all techniques was advanced physiological root resorption and early exfoliation of the root filled teeth with 5 teeth showing physiological mobility at the 24 month follow-up appointment and 4 at the 18 month follow-up appointment. These were mostly in the pulpotomy group. Five teeth also exfoliated during the study with the majority again being in the pulpotomy group.

7.4 To assess the feasibility of patient recruitment, cooperation with treatment and return for follow-up appointments

Recruitment of patients from a single centre was difficult and the target sample size was not recruited within the timespan of this project (one year). At the Lyng Health Centre 109 children were assessed as suitable from their referral letters, 62 attended for assessment appointments and only 11 children were recruited to the study. This gave a recruitment rate of 10.1% from referral letters and 17.7% from attendance in clinic.

The most common reason for failure to recruit was that the child had no non-vital primary molars on assessment which could be predicted from the percentage of children having non-vital primary teeth in the population (3-4%)(Innes et al., 2013, Health and Social Care Information Centre, 2015, Davies et al., 2012). The other reasons for non-recruitment were insufficient cooperation for treatment to be carried out according to the research protocol or to have radiographs taken which showed the periapical area.

Once recruited and randomly allocated to groups, 2 out of 7 children in the pulpectomy group and 1 out of 8 children in the pulpotomy group were not cooperative enough to complete the treatment. In the pragmatic treatment group 4 out of 6 children tolerated local anaesthetic placement but none tolerated rubber dam which suggests this is the most difficult aspect of the treatment for children to manage. 10 out of 16 children completing treatment gave a positive rating of the experience with only one negative response from the pragmatic treatment group.

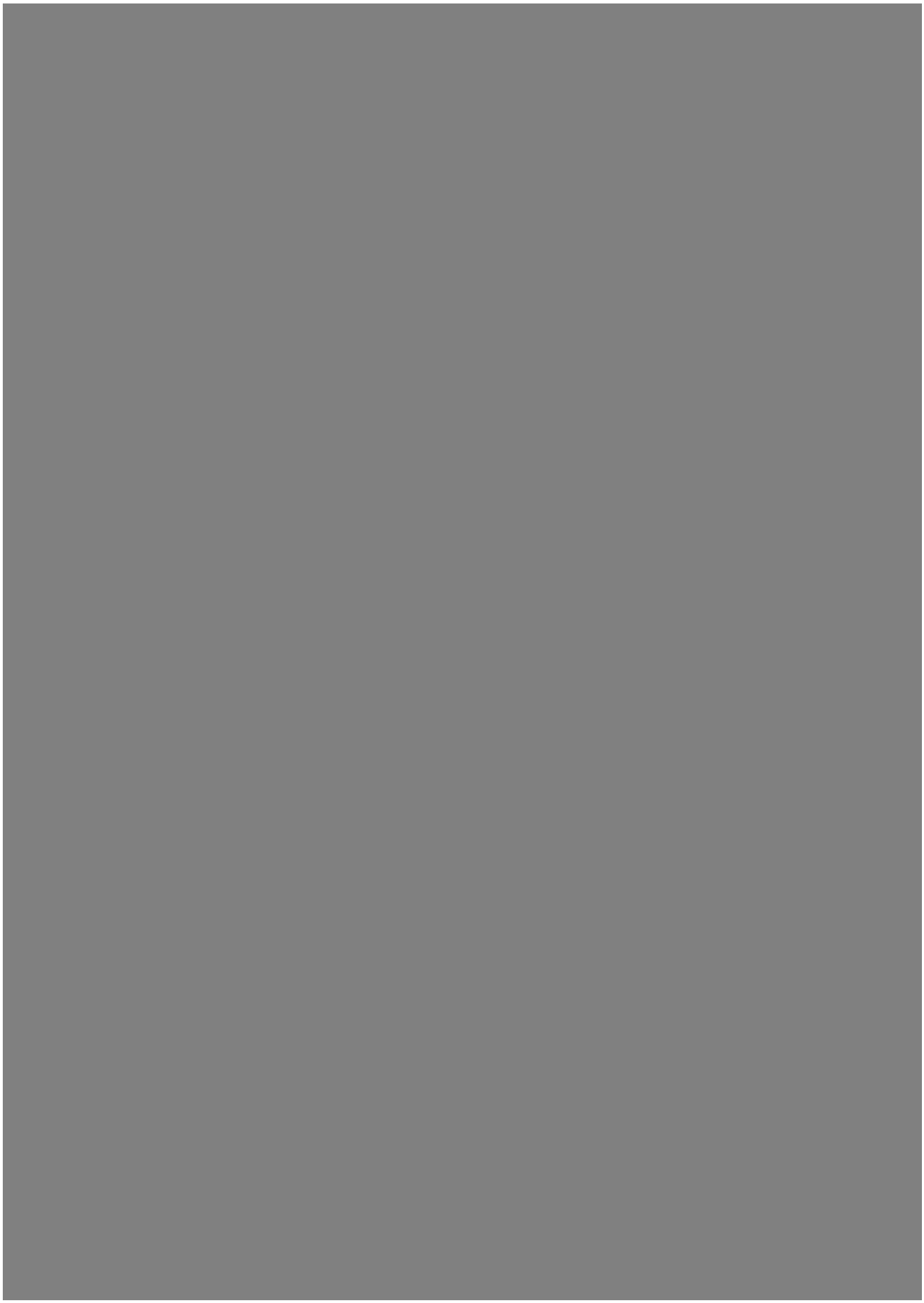
Thirteen teeth out of 16 (81.3%) who completed treatment were followed up until exfoliation or extraction or for 24 months. This was a good retention rate. However not all follow-up appointments were completed at the intervals in the protocol (6 months, 12 months, 18 months and 24 months). This was for a variety of reasons including availability of research staff for follow-up appointments, children missing or cancelling one appointment and no appointment available for several weeks or months and children with multiple teeth in the study. This also meant that radiographs were not taken at all follow-up appointments to limit the radiographic exposure to the child.

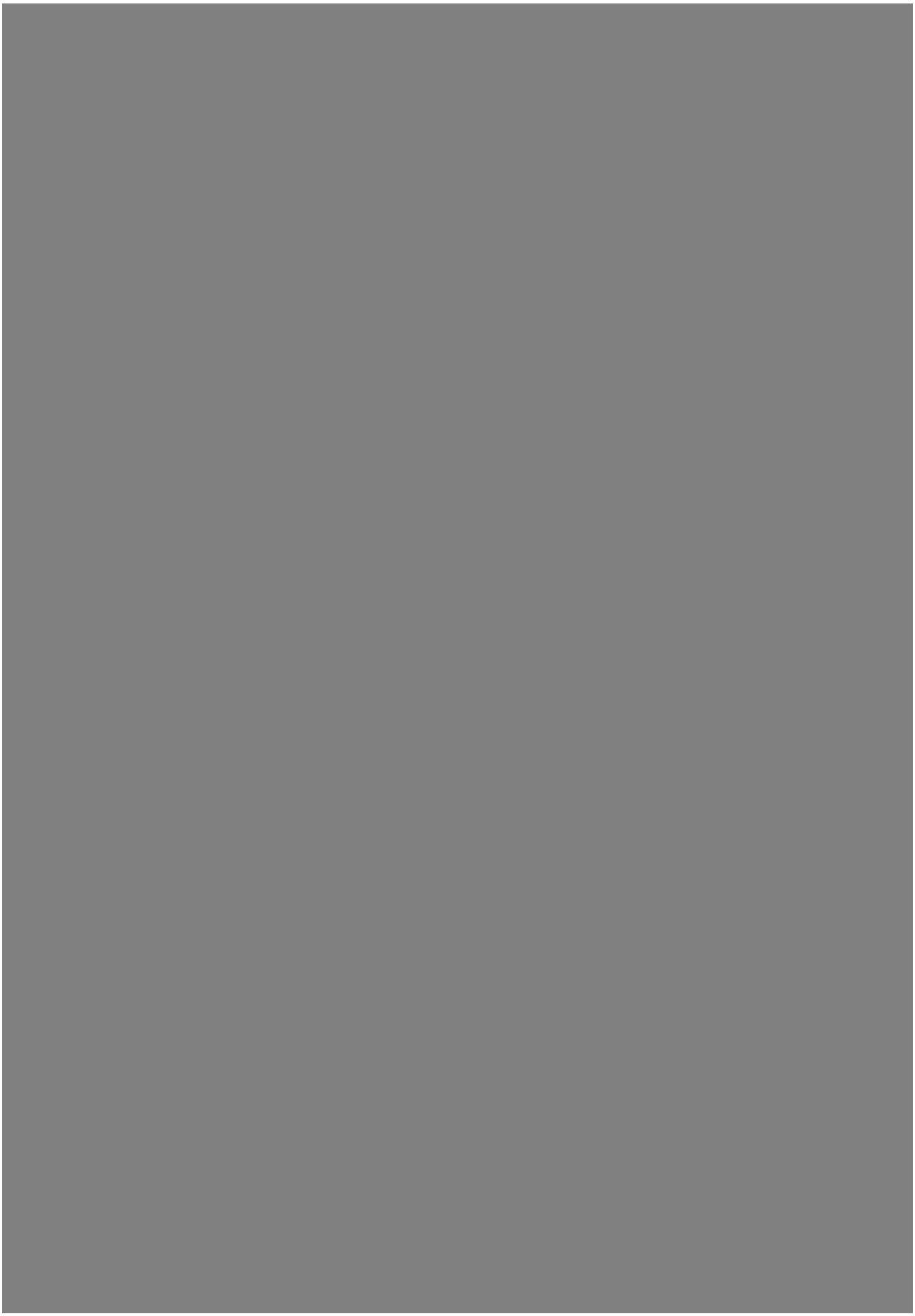
7.5 Recommendations for further work

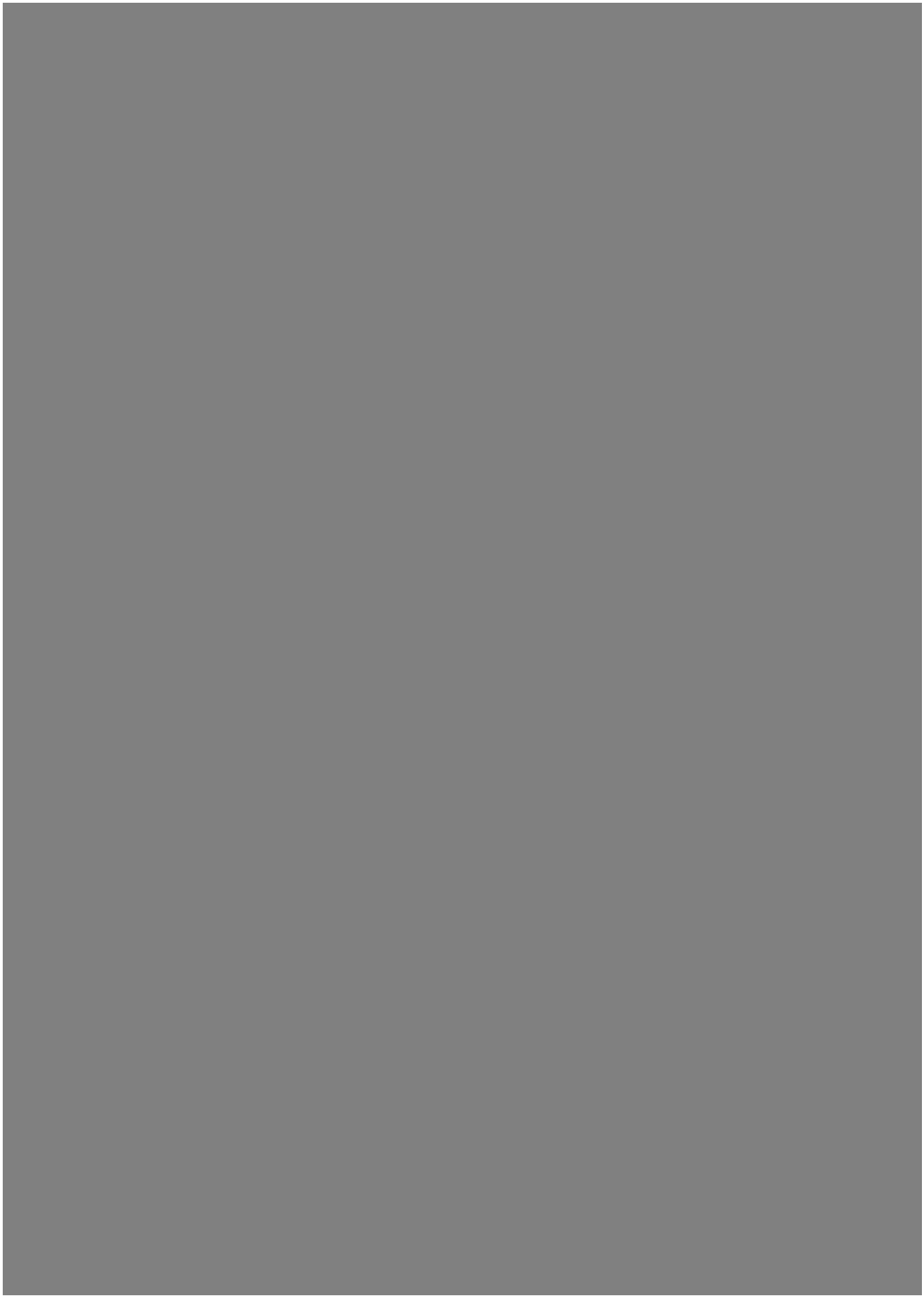
This pilot study has highlighted the potential of alternative pulpotomy techniques to treat non-vital primary molars in children with limited cooperation. These results suggest that a Scottish/ non-root canal instrumentation pulpotomy appears to be at least as successful as a pulpectomy when using chlorhexidine irrigation and Vitapex® obturation over a 2 year follow-up period. When rubber dam isolation is not possible a pragmatic pulpotomy appears successful over a 1 year follow-up. However the numbers are too small to draw meaningful conclusions. The most reliable evidence for the success of these techniques would be gained from a randomised controlled trial but in order to recruit sufficient numbers of children a multicentre trial would be needed alongside alternative means of recruitment from general dental practitioners, student clinics and referrals for GA. This would have implications for the standardisation of the techniques and data collection.

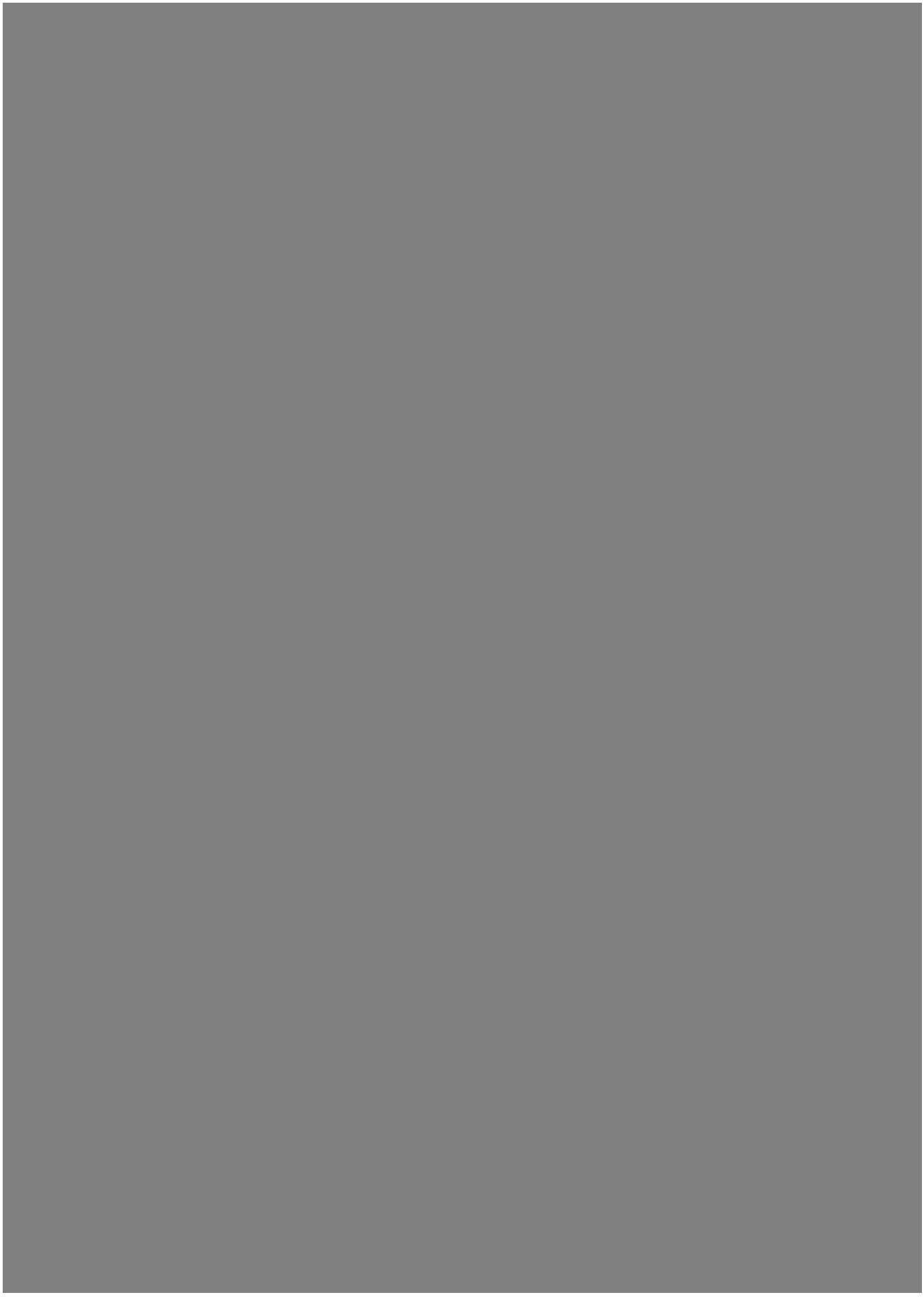
Recruitment could also be improved by changing the study design to an observational design rather than a randomised controlled trial. This would reduce the strength of the evidence but would increase recruitment as children would not need to be able to cooperate with a pulpectomy to be enrolled in the study. They could have the treatment they were able to tolerate with the most cooperative children having pulpectomies and least cooperative having Scottish pulpotomies without rubber dam. It would also reduce the need for preoperative radiographs showing the periapical area. An electronic apex locator could also improve the accuracy of working length determination and reduce the radiographic exposure of the children. The retention rates were good in this study and 2 years appears to be an appropriate length of time to assess the success of the treatment. Clinical signs were more important in determining success than radiographic signs but radiographs should be taken wherever possible to give a full picture of the resolution or progress of infection and inflammation.

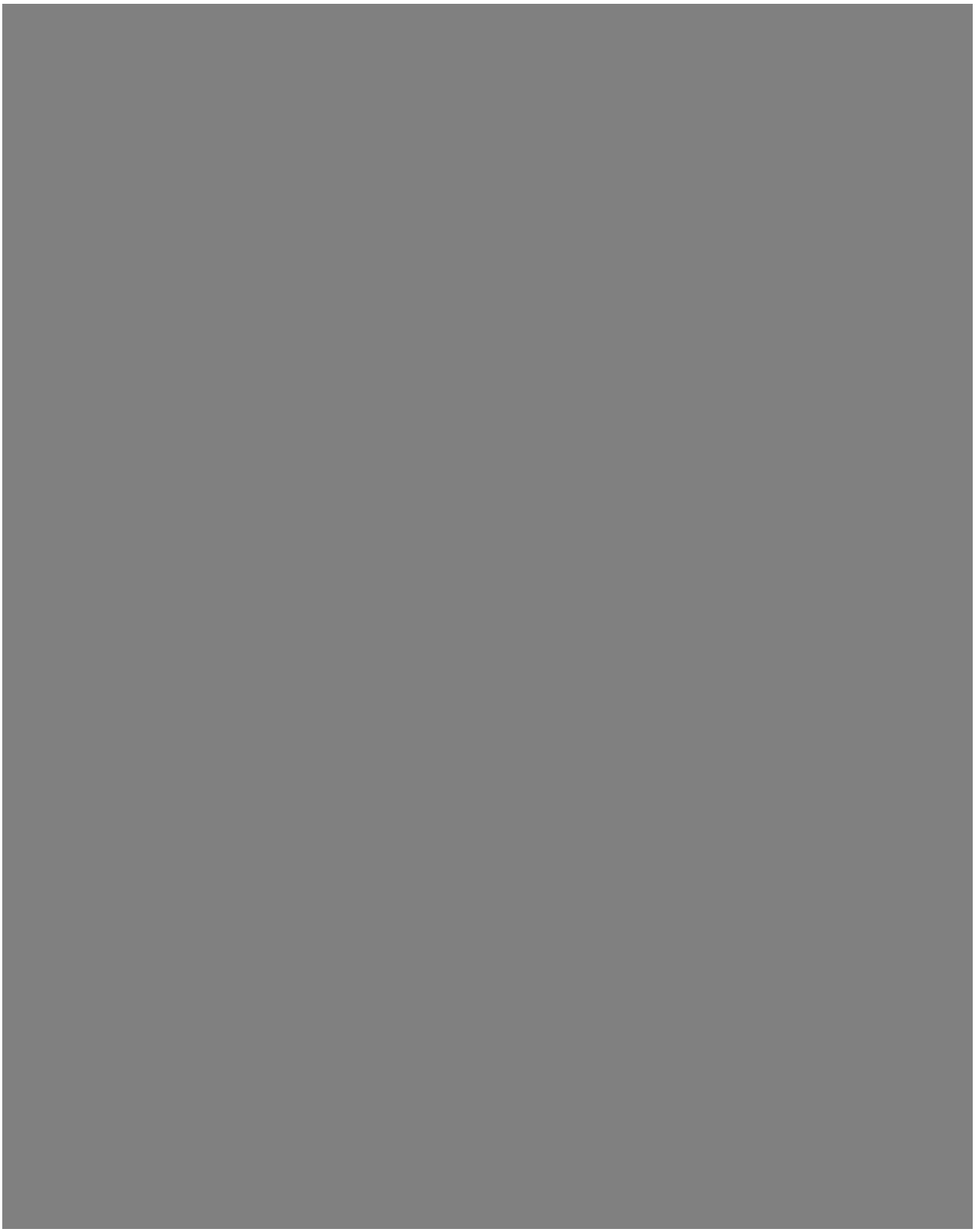
Further analysis of the exfoliated and extracted teeth microscopically may give further explanation of the reasons for accelerated physiological resorption and early exfoliation of the teeth especially when treated by non-root canal instrumentation pulpotomy. It will also aid understanding of the process of inflammation at the periapical and furcation regions and how infection and inflammation are managed when the root canals are not instrumented and necrotic and infected pulp tissue is potentially left in the canals.

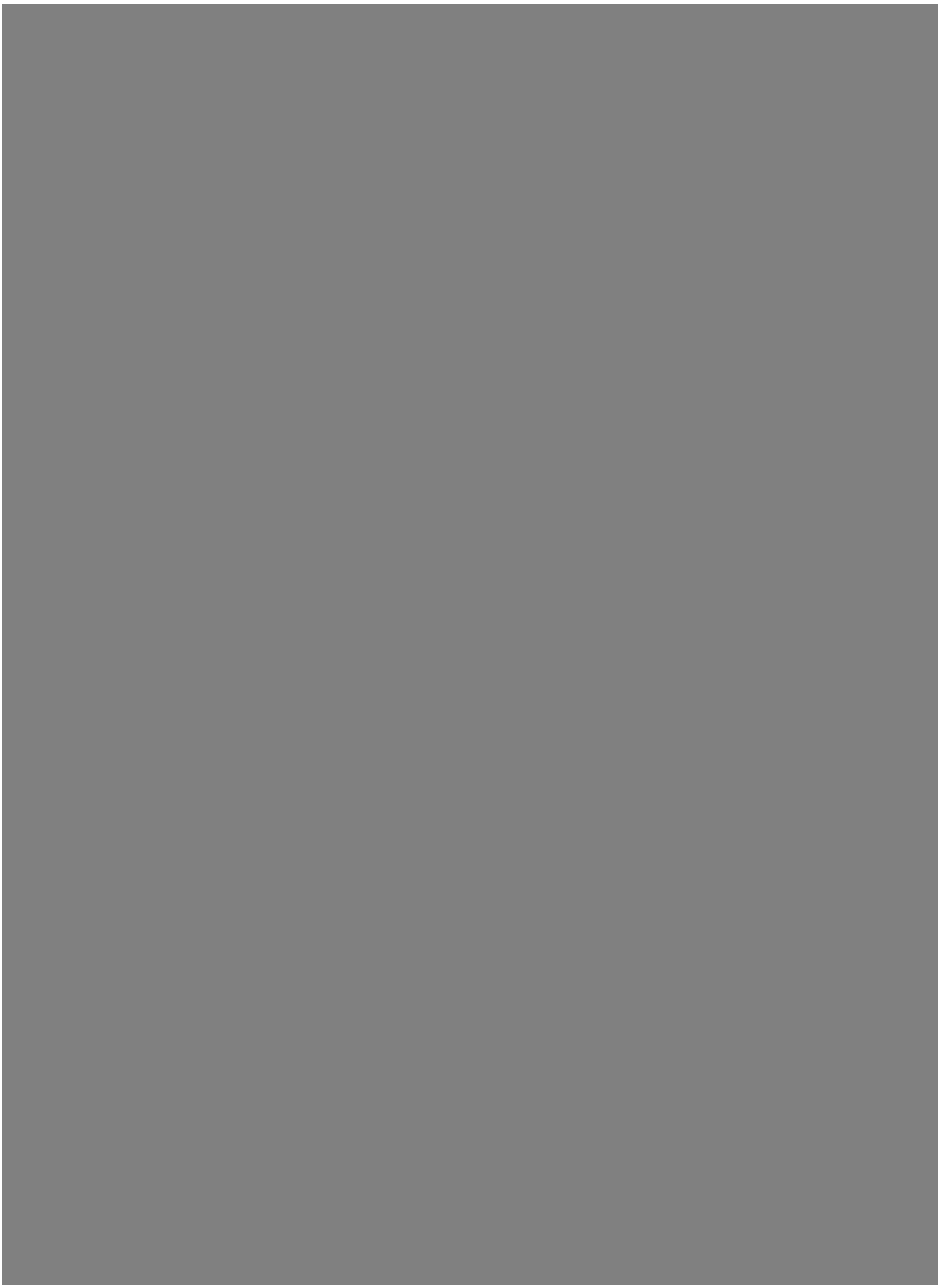


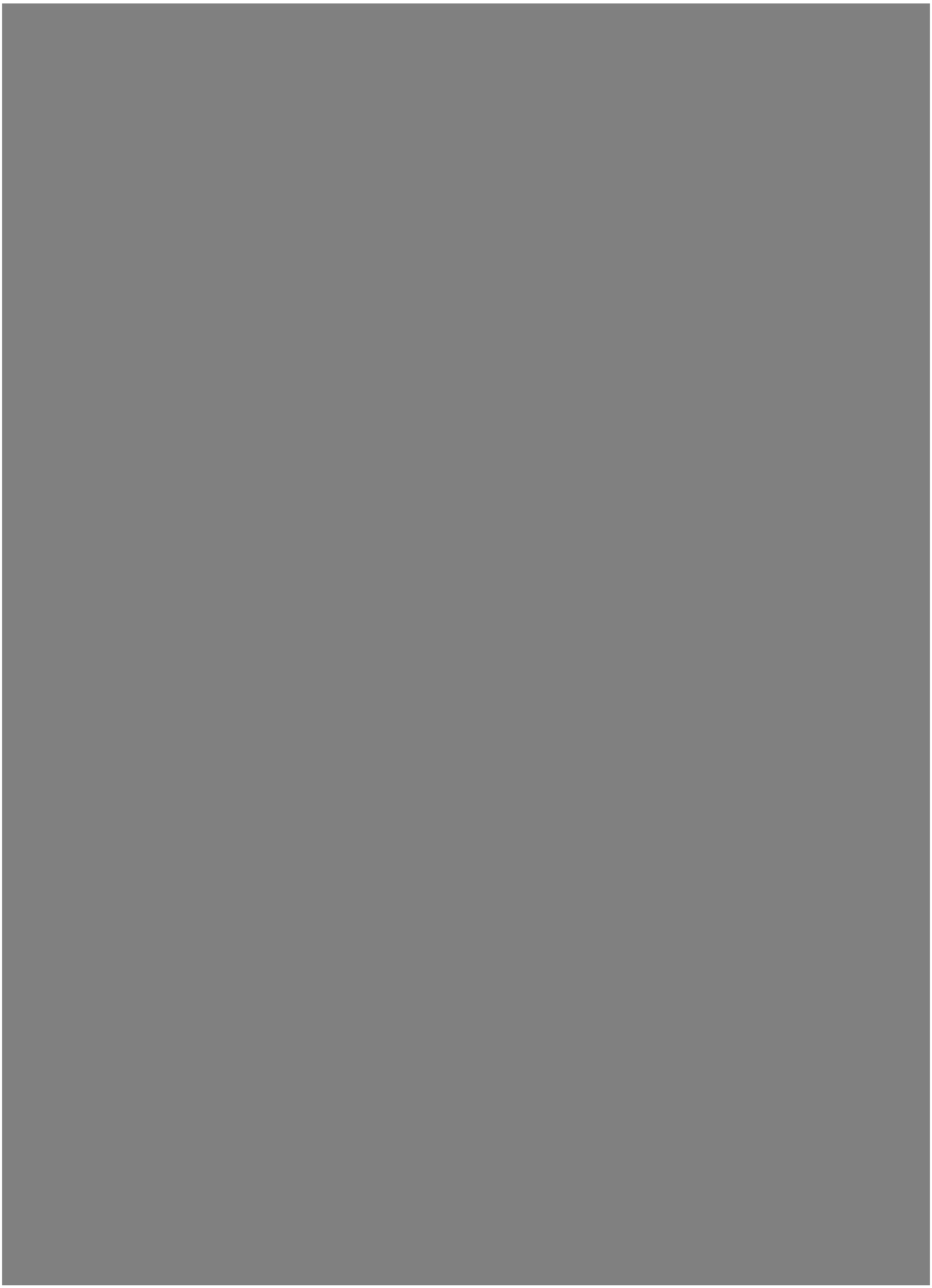


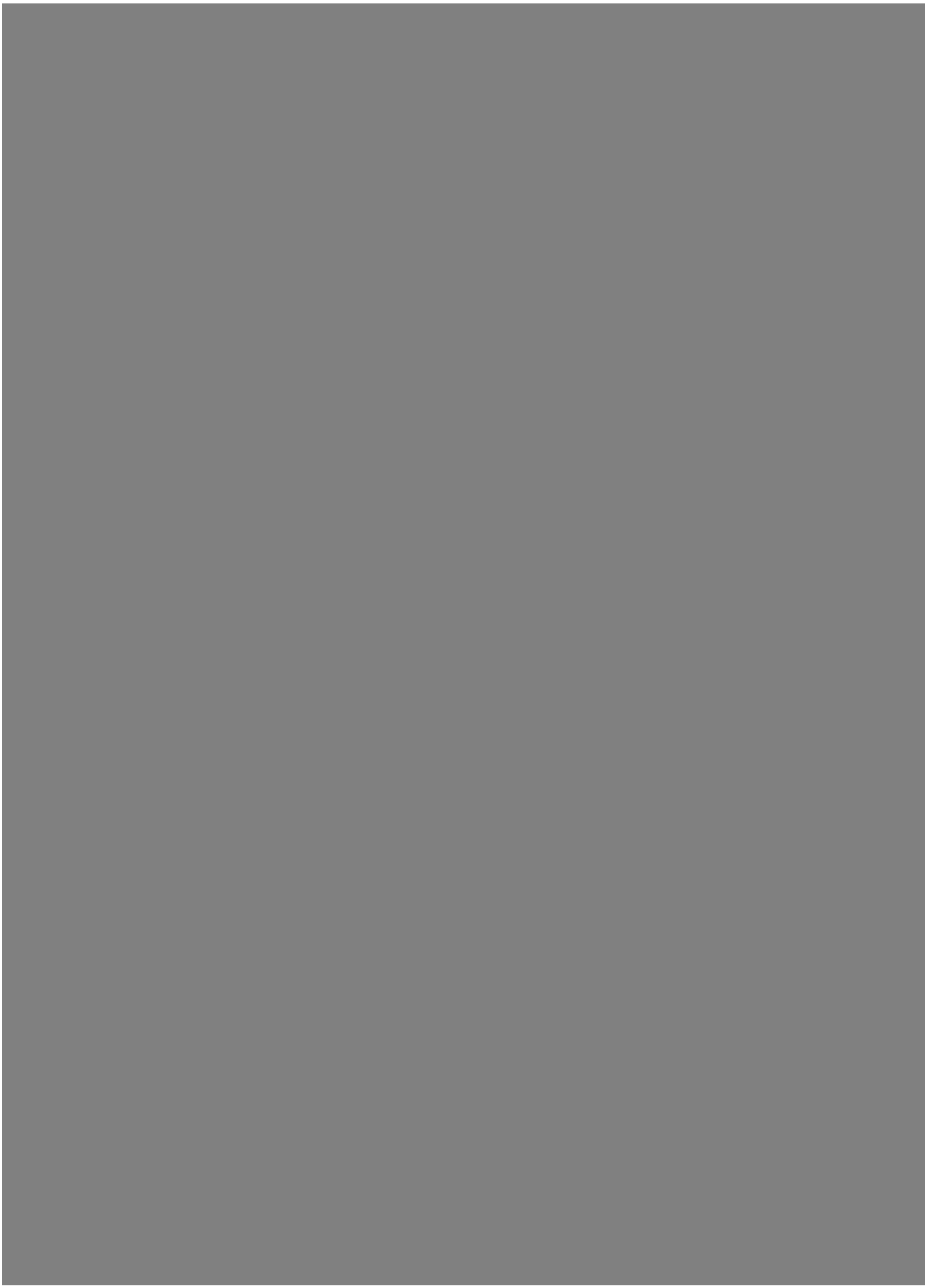


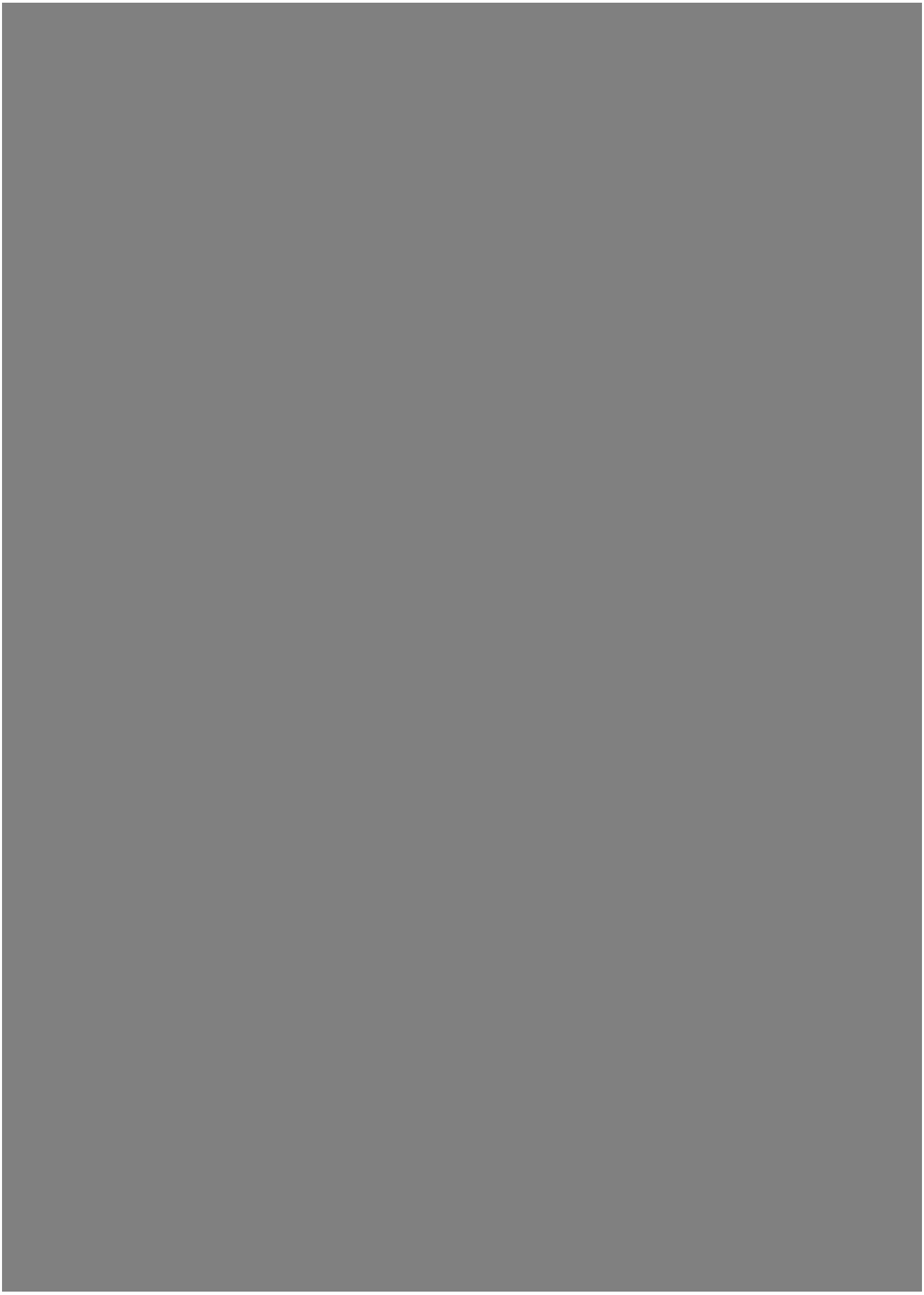


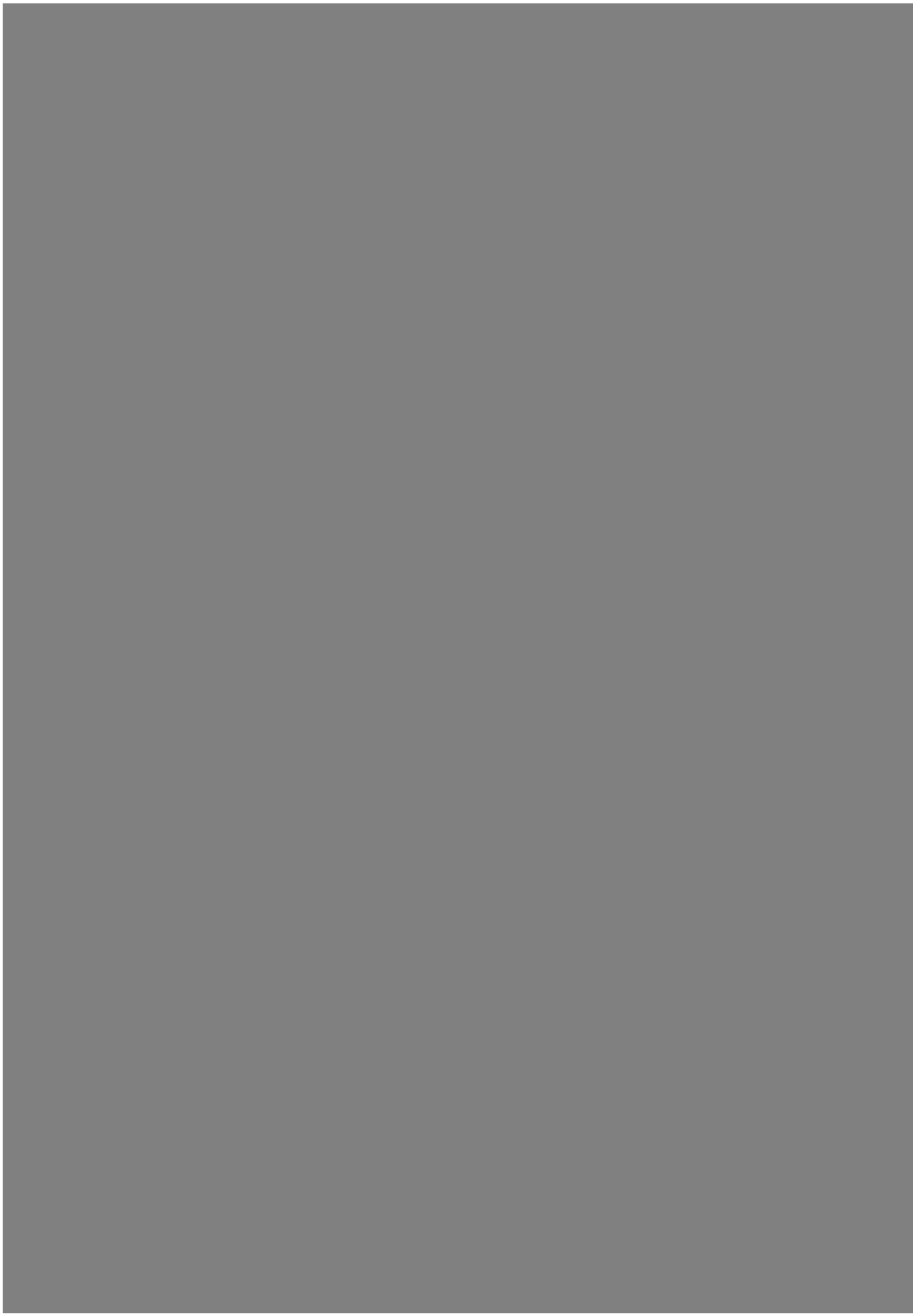


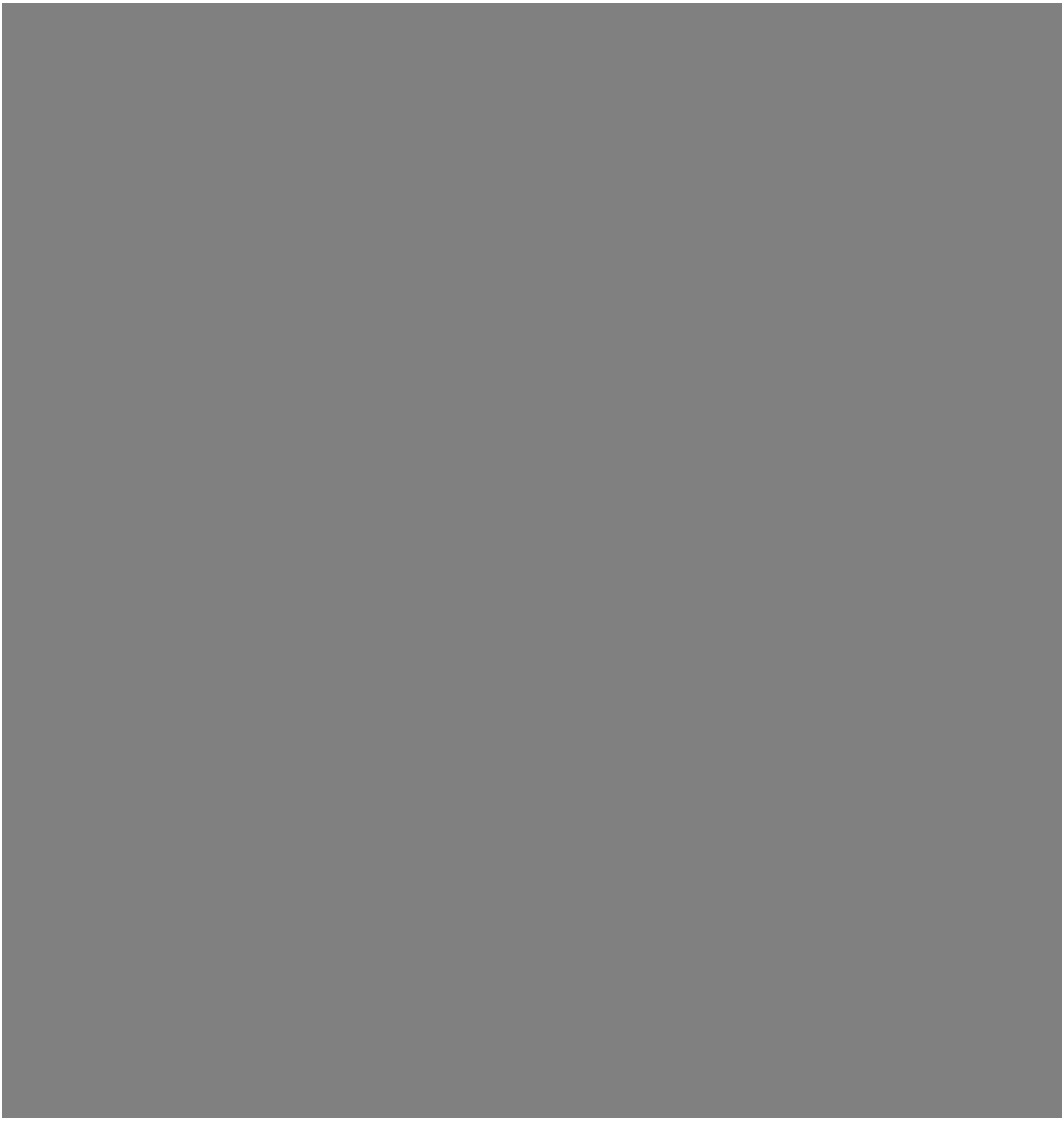


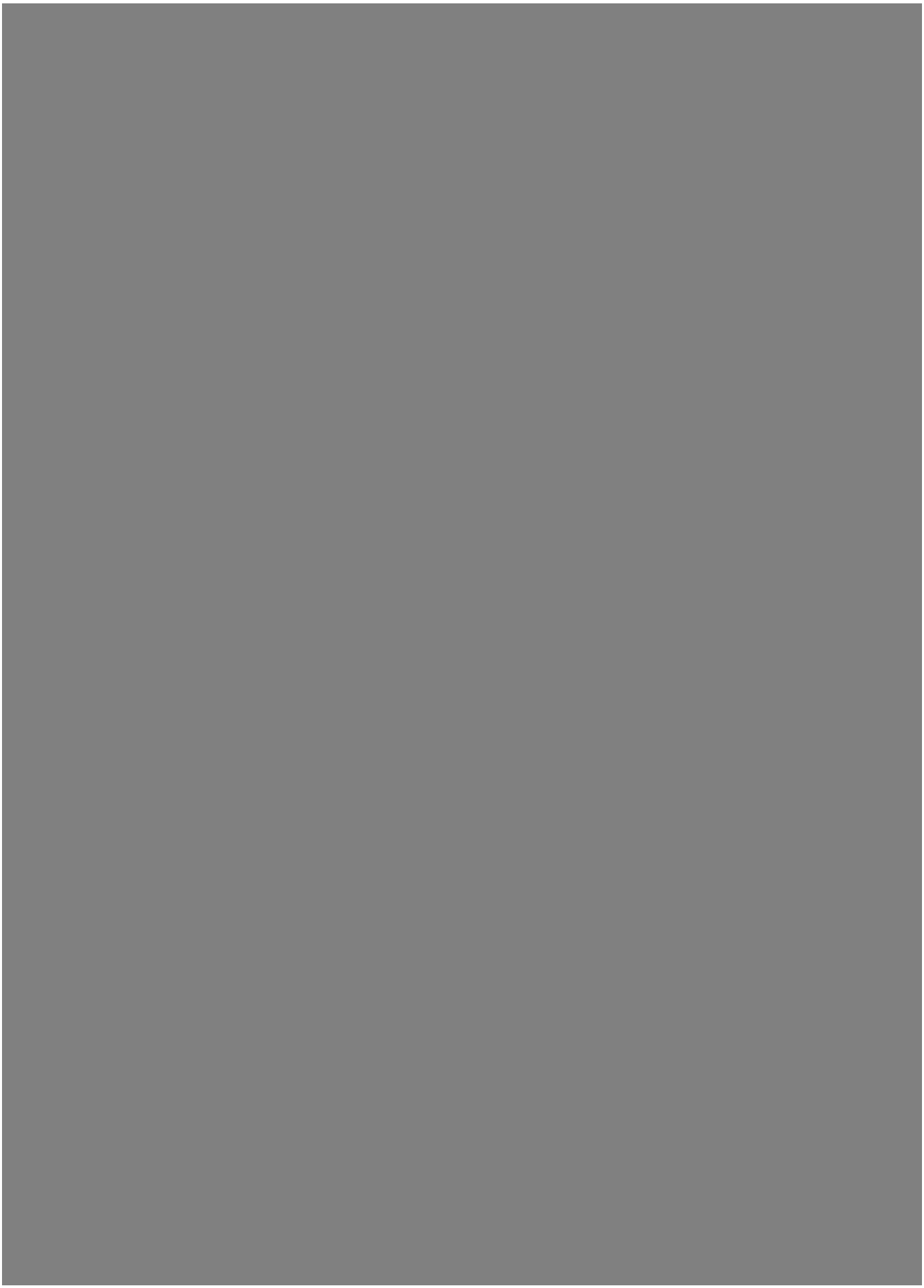


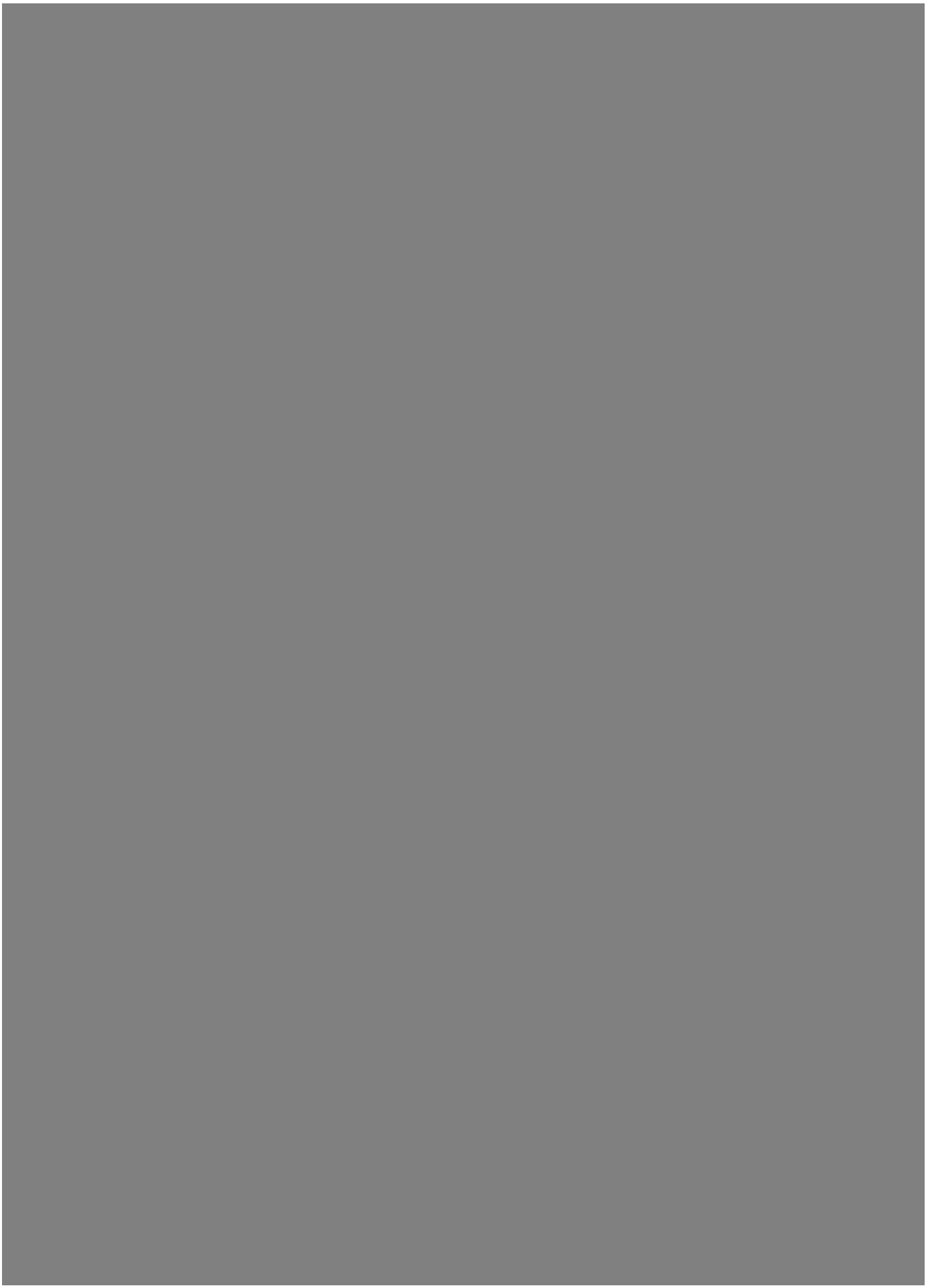


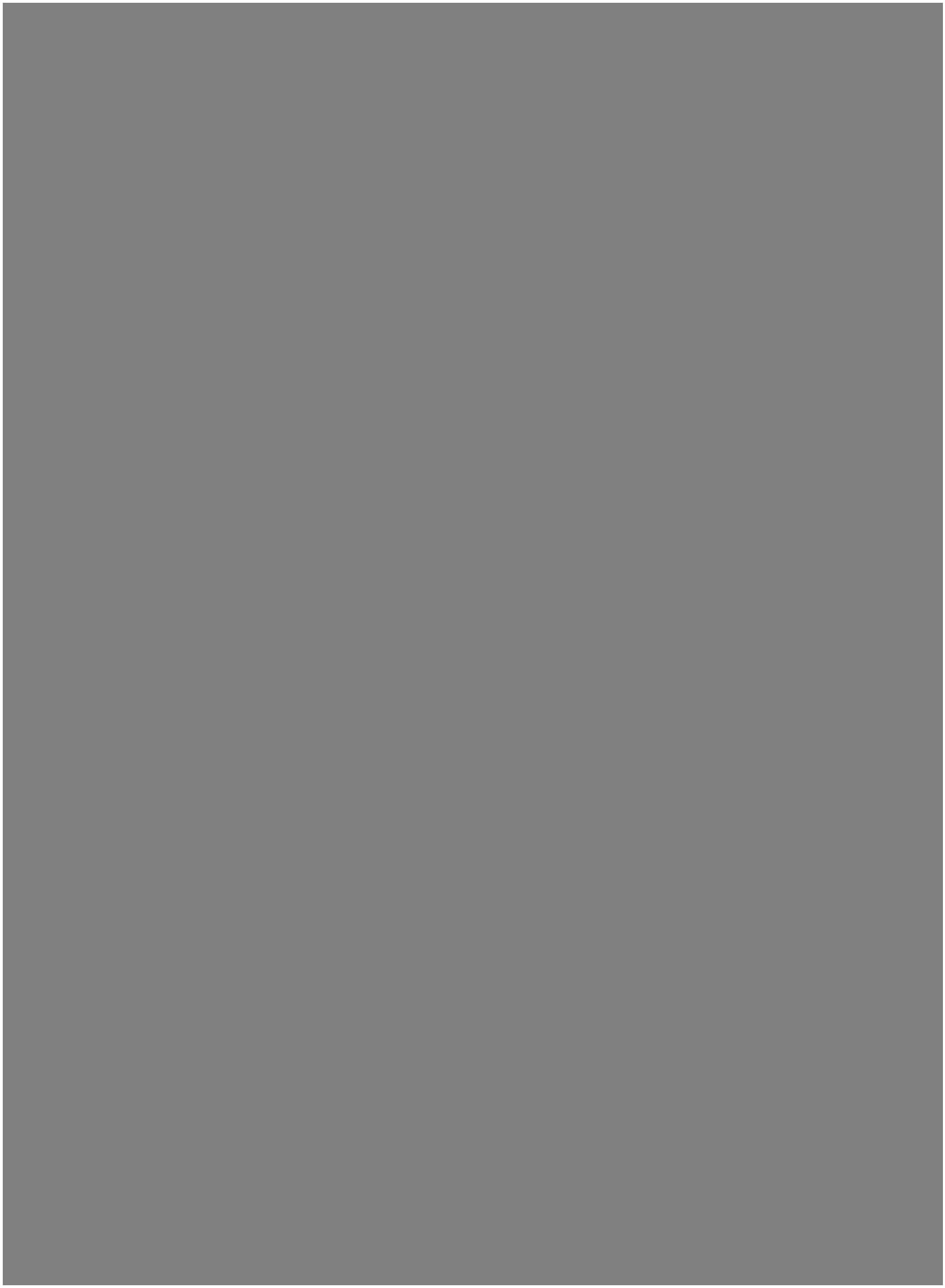












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